High Energy Dilepton Experiments

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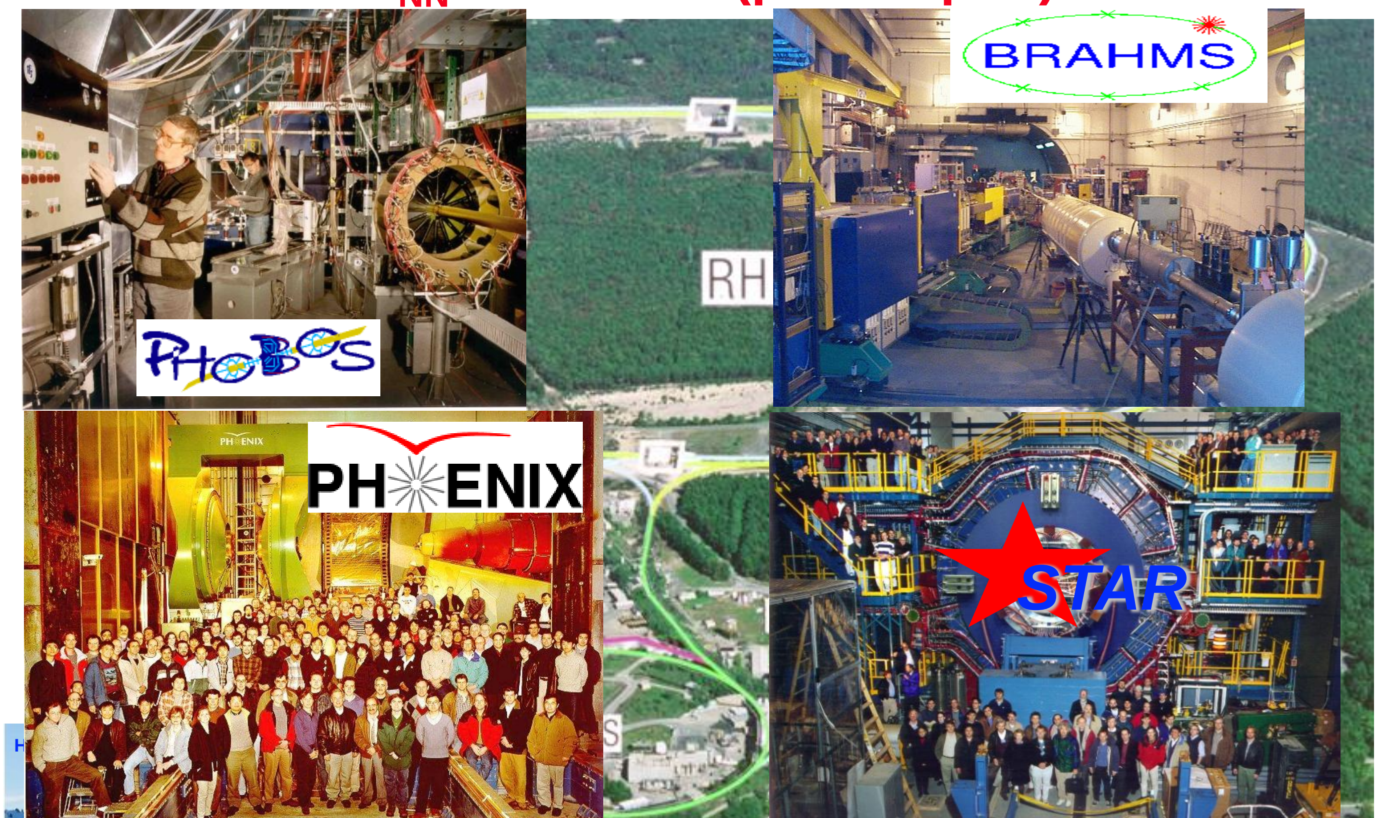
RHIC

- **RHIC = Relativistic Heavy Ion Collider**
- **located at Brookhaven National Laboratory**

RHIC and its experiments

- what's so special about RHIC?
  - it's a collider
    - no thick targets
    - detector systematics do not depend on E_{CM}
  - p+p: $\sqrt{s} \leq 500$ GeV (polarized beams)
  - A+A: $\sqrt{s_{NN}} \leq 200$ GeV (per NN pair)



- experiments with specific focus
  - BRAHMS (until Run-6)
  - PHOBOS (until Run-5)
- multi purpose experiments
  - PHENIX
  - STAR

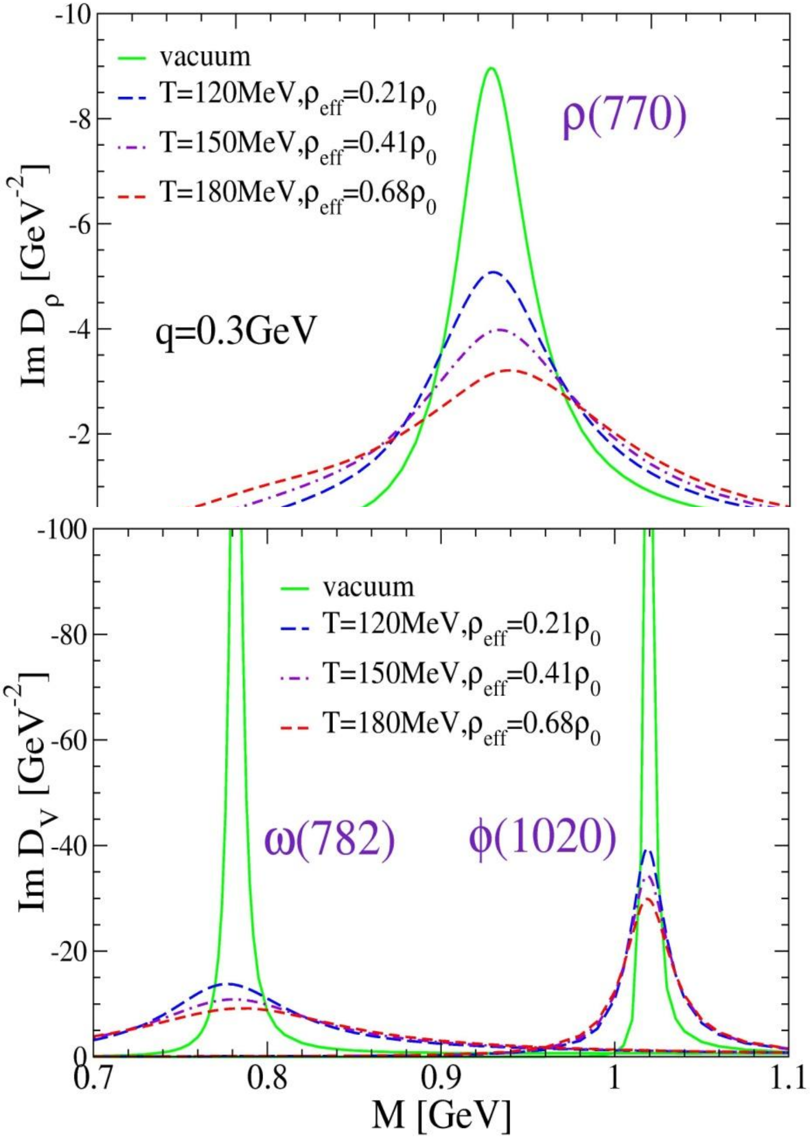
Low mass e^+e^-: prospects @ RHIC

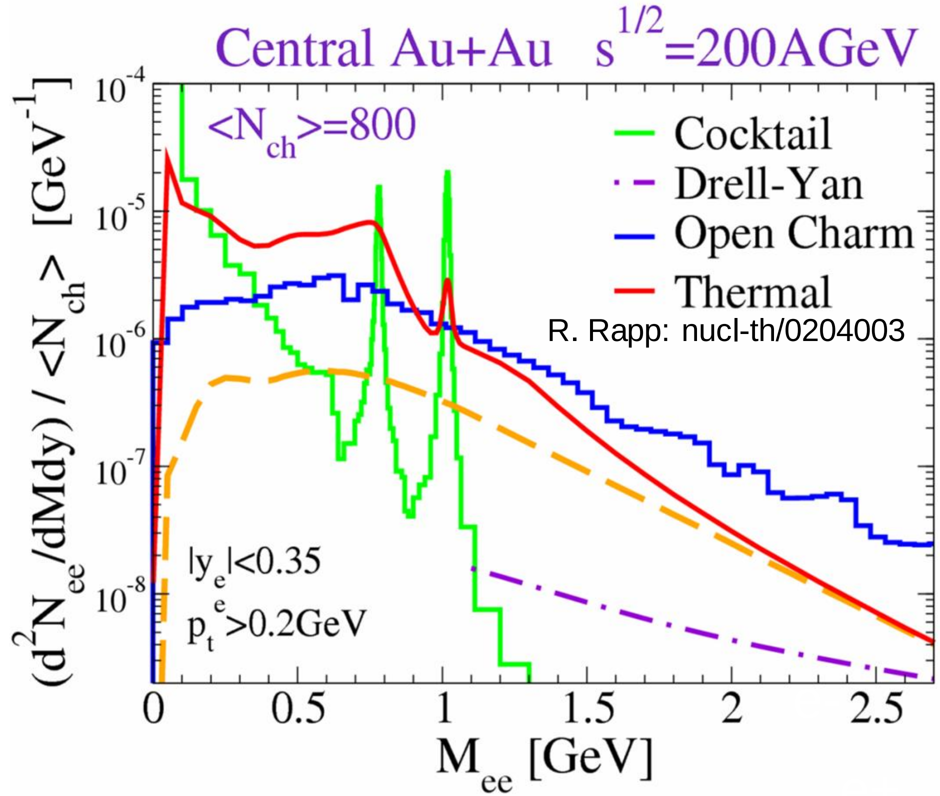
- **2 scenarios @ SPS profit from high baryon density**
  - dropping ρ mass
  - broadening of ρ
- **what to expect at RHIC?**

	SPS (Pb-Pb)	RHIC (Au-Au)
$dN(\bar{p})$ / dy produced baryons ($p, \bar{p}, n, \bar{n}$)	6.2 24.8	20.1 80.4
$p - \bar{p}$ participants nucleons $(p - \bar{p})A/Z$	33.5 85	8.6 21.4
	110	**102**

- **baryon density: almost the same at SPS & RHIC (although the NET baryon density is not!)**

e^+e^-: theoretical guidance at RHIC



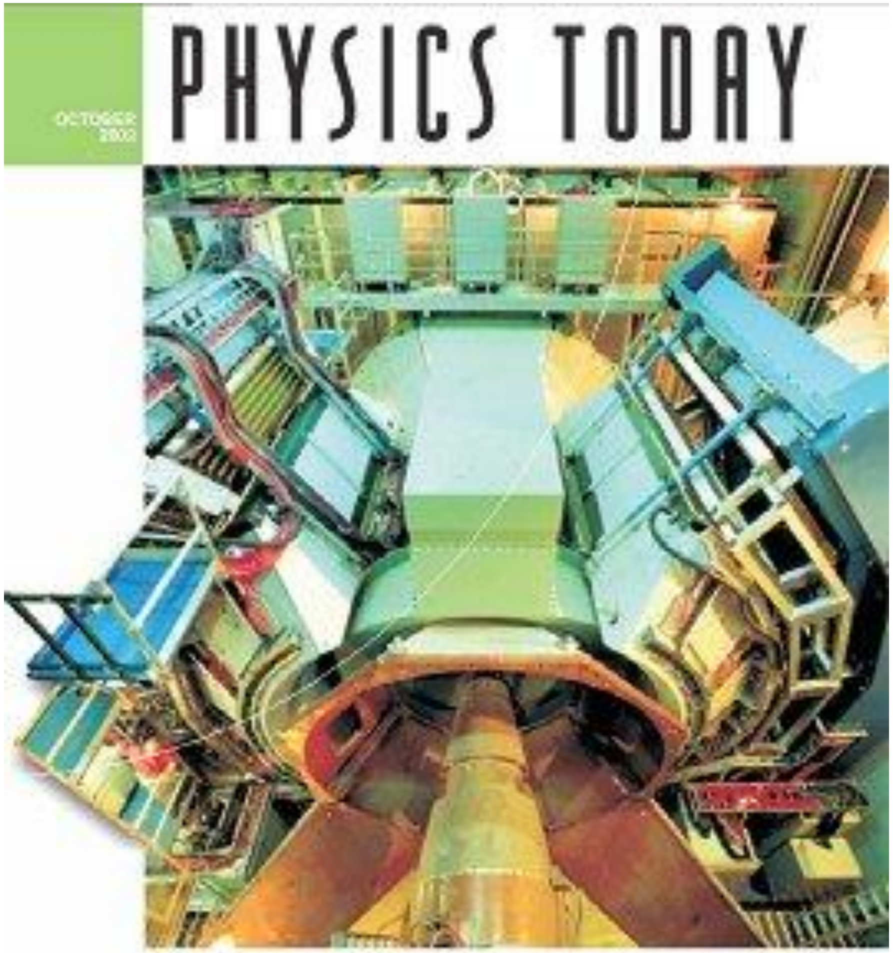


- in-medium modifications of vector mesons persists
- open charm contribution becomes significant

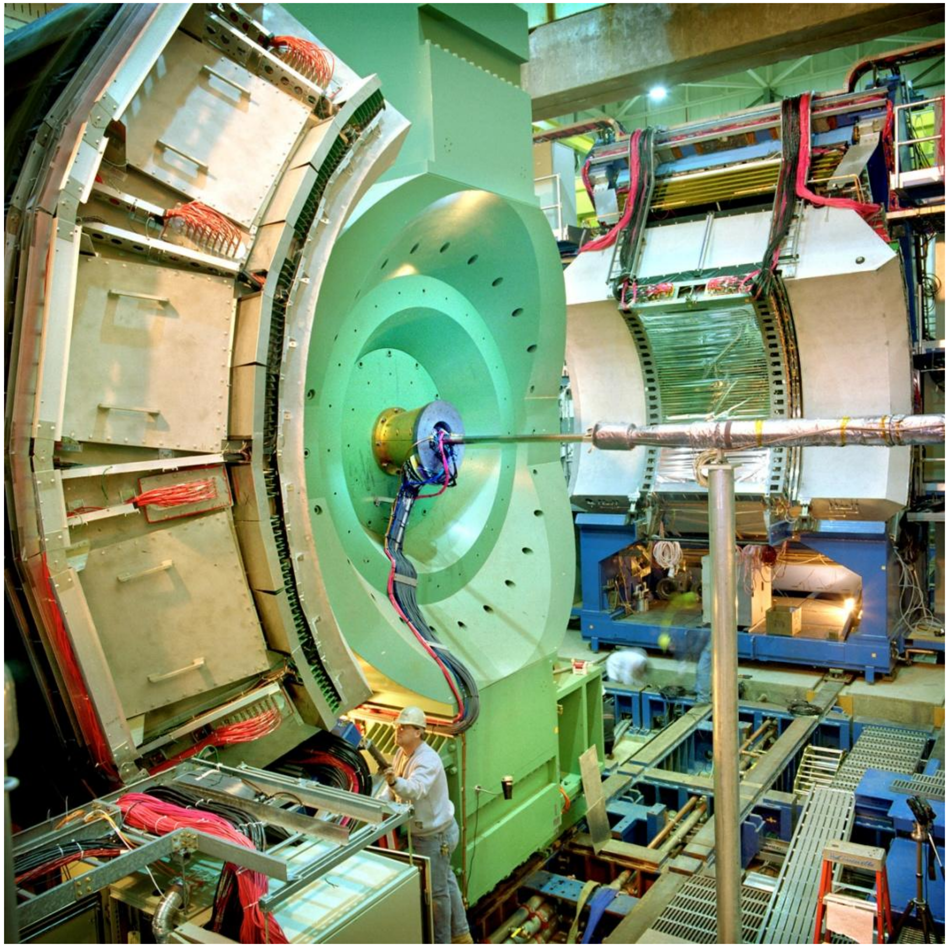
The founding fathers' view

- **before 1991**
  - **proposals for various experiments at RHIC**
    - STAR, TALES, SPARC, OASIS, DIMUON …
    - except for STAR everything else is burned down
  - **from the ashes rises PHENIX**
    - **P**ioneering **H**igh **E**nergy **N**uclear **I**nteraction e**X**periment
- **1991: PHENIX "conceptual design report"**
  - **philosophy**
    - measure simultaneously as many observables relevant for QCD phase transitions as you can imagine
    - all but one: low-mass dielectrons
  - **why no dielectrons?**
    - included in first TALES proposal
    - considered to be "too difficult" for PHENIX
- **a lot of work can make impossible things happen**

PHENIX in practice

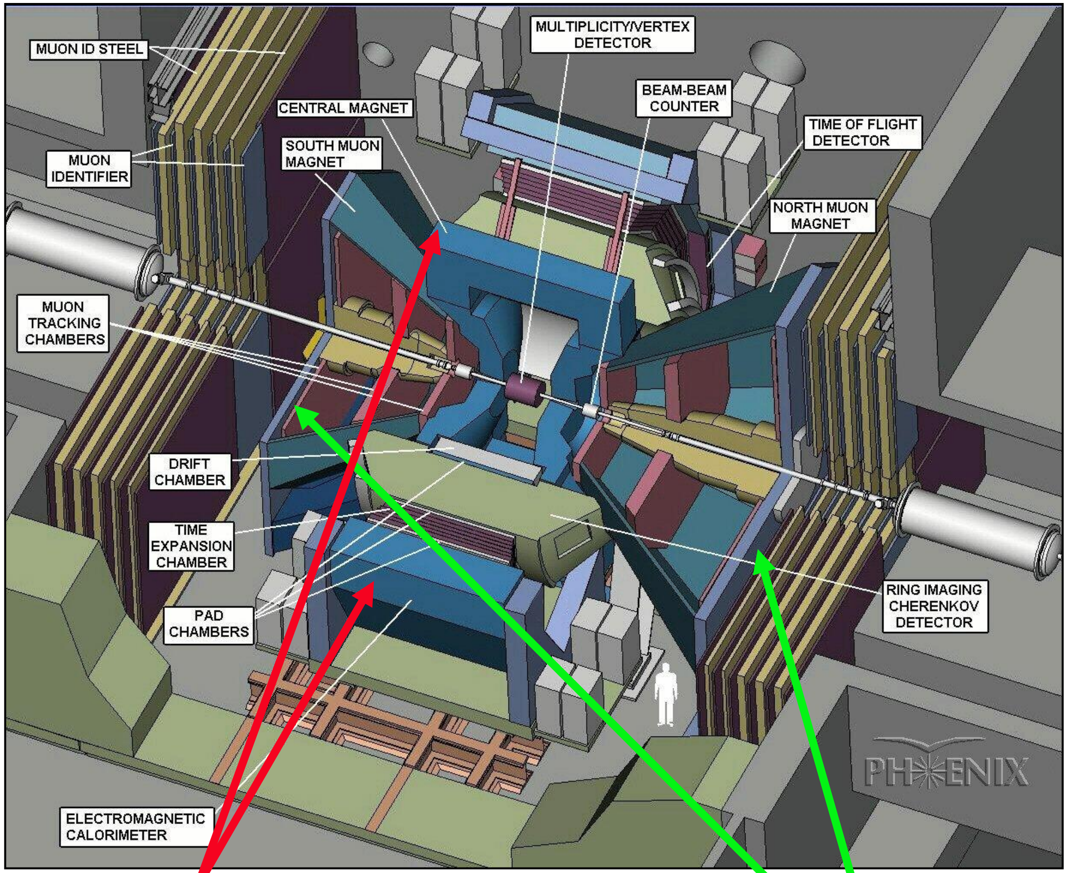


Nuclear matter in extremis



PHENIX in principle

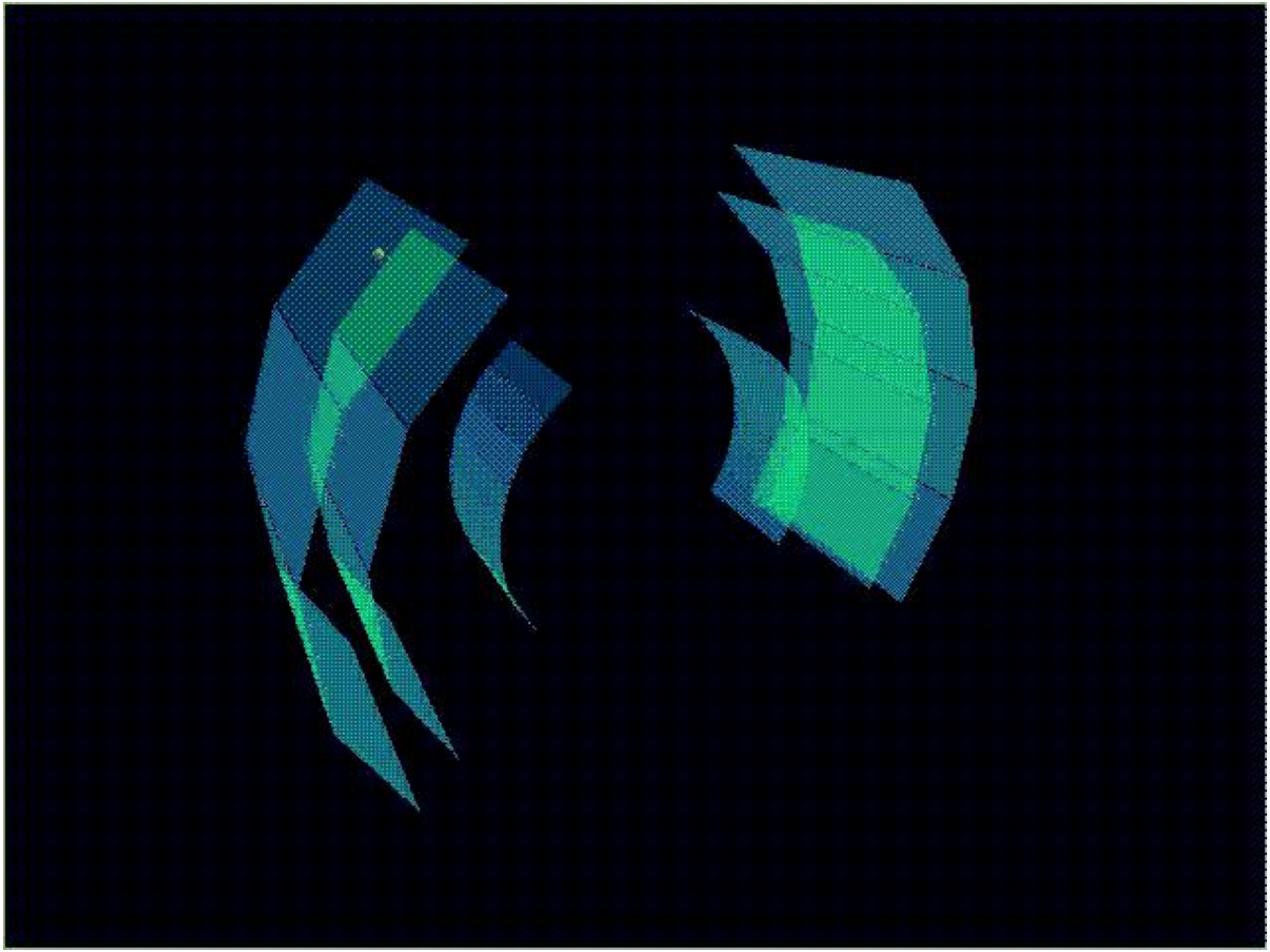
- 3 detectors for global event characterization
- central spectrometers
  - measurement in range:
    $|\eta| \leq 0.35$
    $p \geq 0.2$ GeV/c
- forward spectrometers
  - muon measurement in range:
    $1.2 < |\eta| < 2.4$
    $p \geq 2$ GeV/c



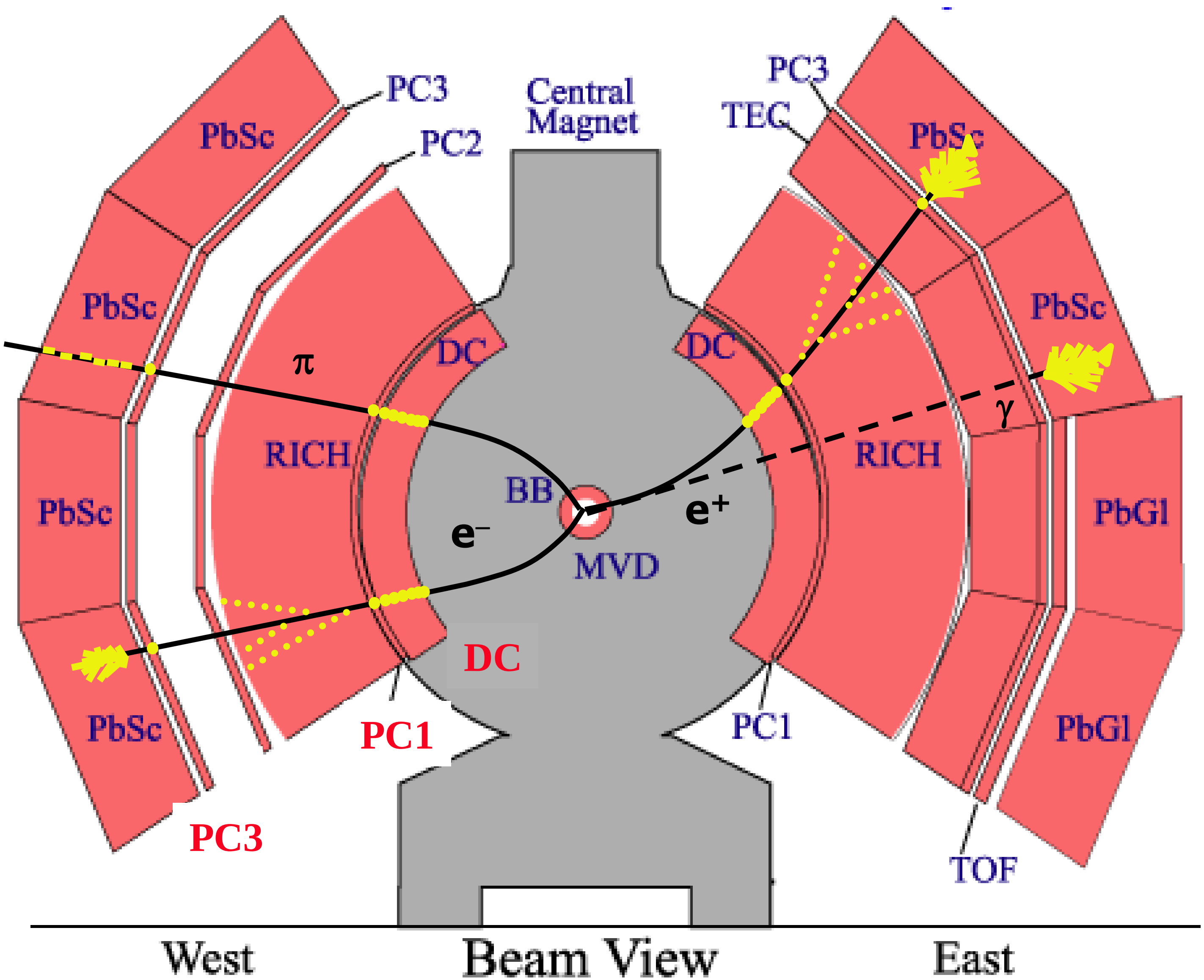
two central electron/photon/hadron spectrometers

two forward muon spectrometers

Au-Au collision as seen in PHENIX

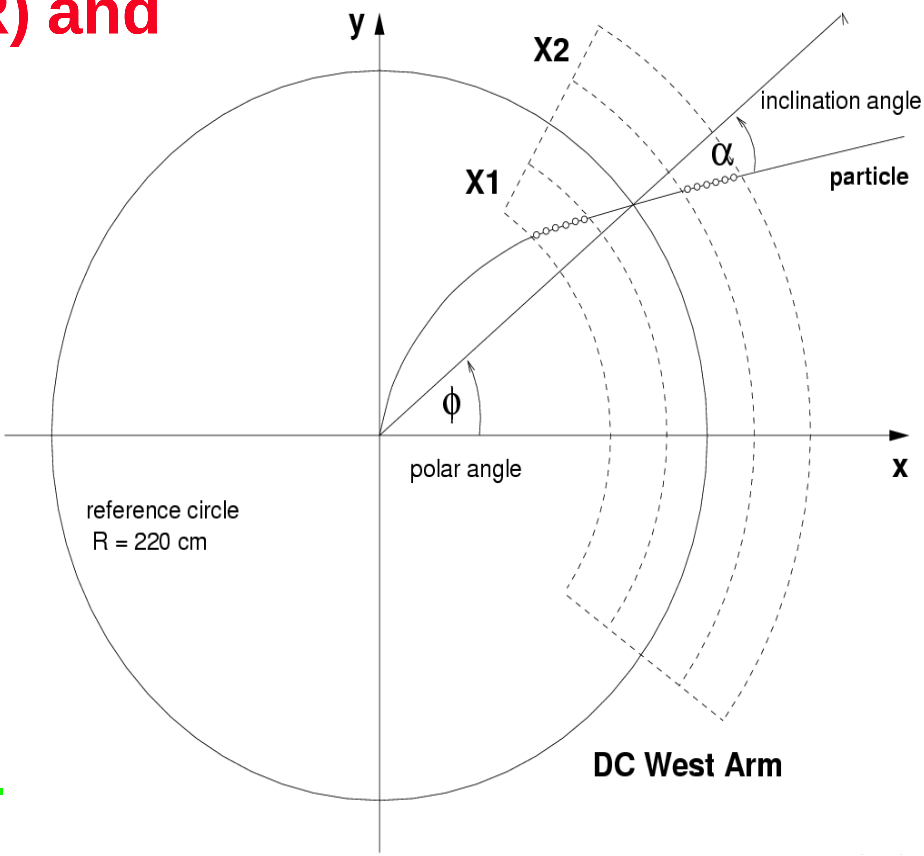


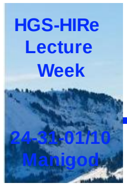
PHENIX: tracking & particle ID



Momentum determination

- Simple relation between bending and momentum
  $\alpha = K/p_T$ K~200 rad GeV/c
- Momentum resolution is determined by the resolution of α, which is determined by :
  - single hit resolution(SHR) and
  - alignment
- SHR is measured to be 150mm, about 0.3 mrad, which corresponds to 0.3/200=0.1% resolution.
- Affected by
  - global and wire alignments





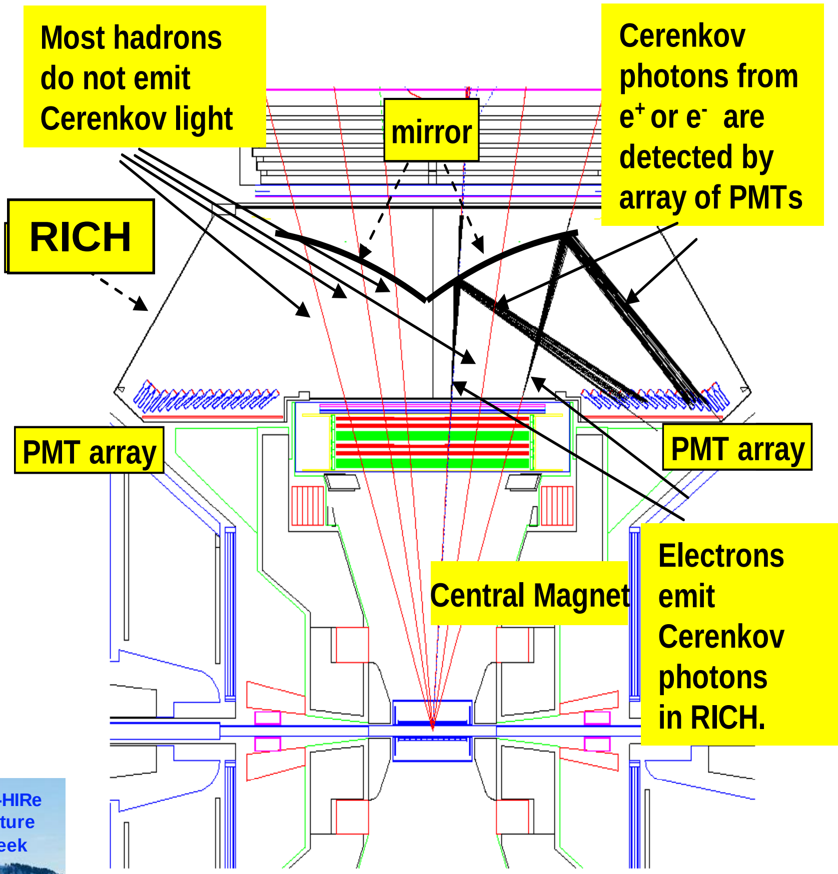
Electron Identification I

Charged particle tracking (dm: 1%)
DC, PC1, PC2, PC3 and TEC

PHENIX optimized for Electron ID

•Cherenkov light RICH +

• shower EMCAL



• emission and measurement of Cherenkov light in the Ring Imaging Cherenkov detector
→ measure of min. velocity

• how can pions ever be mis-identified below 4.9 GeV/c?

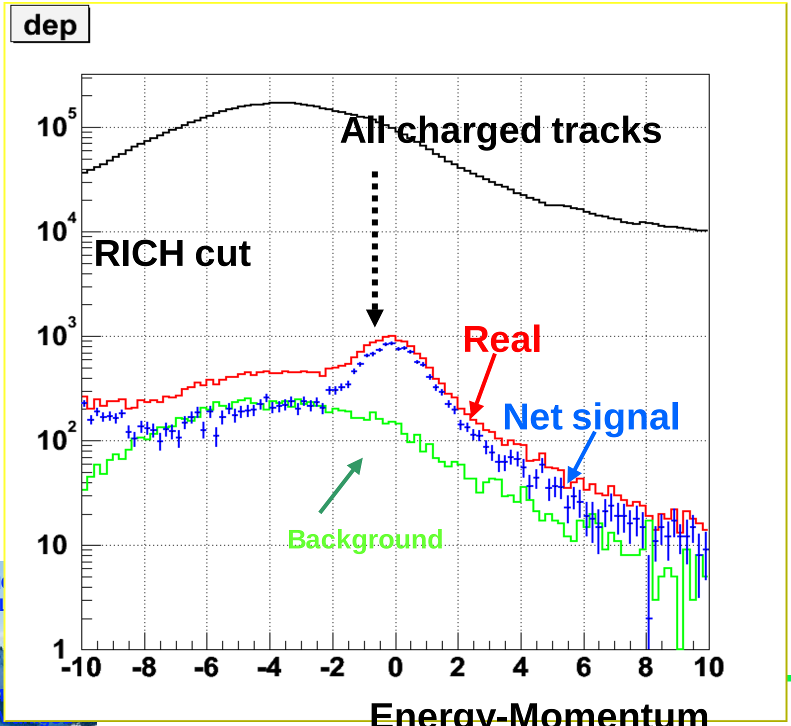
- •Radiation of cherenkov light (≥ 4.9 GeV/c)
- •Production of delta electrons
- •Random coincidence (high multiplicity)
- •spherical mirror

→parallel tracks produce rings at SAME location

Electron Identification II

production and of el.magn. shower in the Electro- Magnetic Calorimeter
→ measure of energy E

- PbSc: sampling cal., layers of lead and scintillator
- PbGl: homogeneous lead-glass volume, Cherenkov radiator



•electron: E ≈ p

•hadron: E < p

•after RICH cuts, clear electron signal

•cut on E/p cleans electron sample!

•background

  •photon conversions

  •random associations (next slide)

•main background source: random combination of hadron track/shower with uncorrelated RICH ring

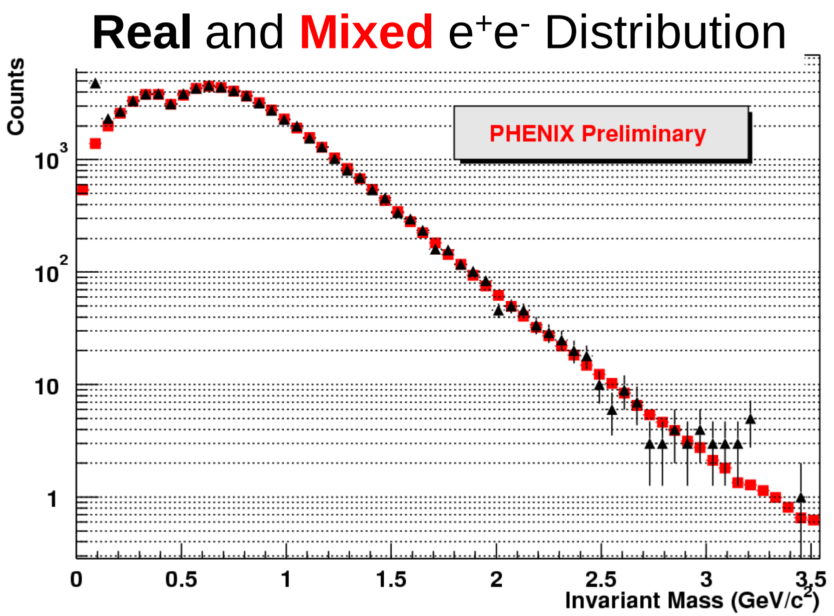
•“standard” subtraction technique: flip-and-slide of RICH

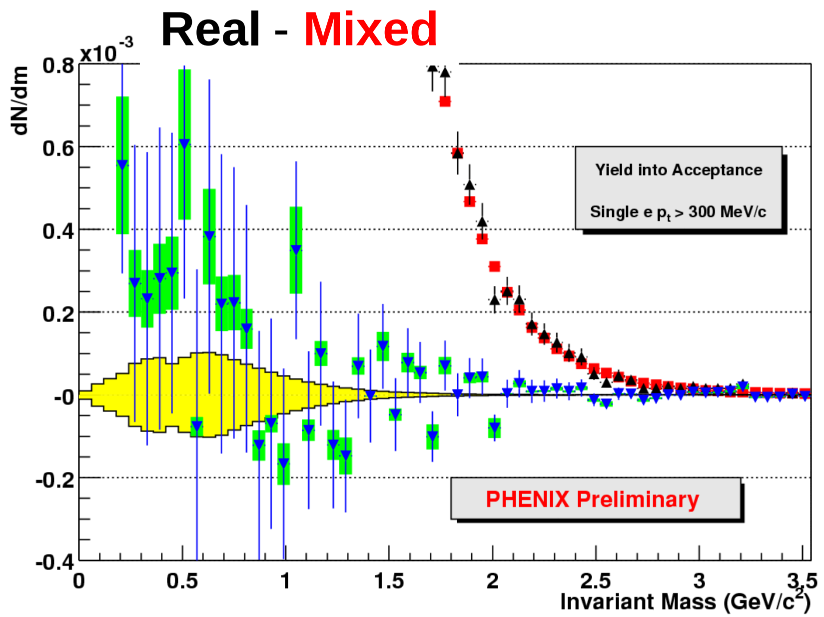
•swapped background agrees in shape with E/p distribution of identified hadrons

•background increases with detector occupancy (can reach ~30% in central Au+Au collisions)

PHENIX measures dielectrons

- first attempt from 2002 Au-Au Run
  - S/B ~ 1/500 (!) for minimum bias events
  - not enough statistics





- Au-Au data taken in 2004
  - ~ 100x statistics
  - photon conversions reduced by factor 2-3
  - expect background reduction by ~ 2

Detailed measurement of the e+e- pair continuum in p+p and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and implications for direct photon production

Detailed measurement of the e^+e^- pair continuum in $p+p$ and Au + Au collisions at $\sqrt{s_{NN}}$=200 GeV and implications for direct photon production

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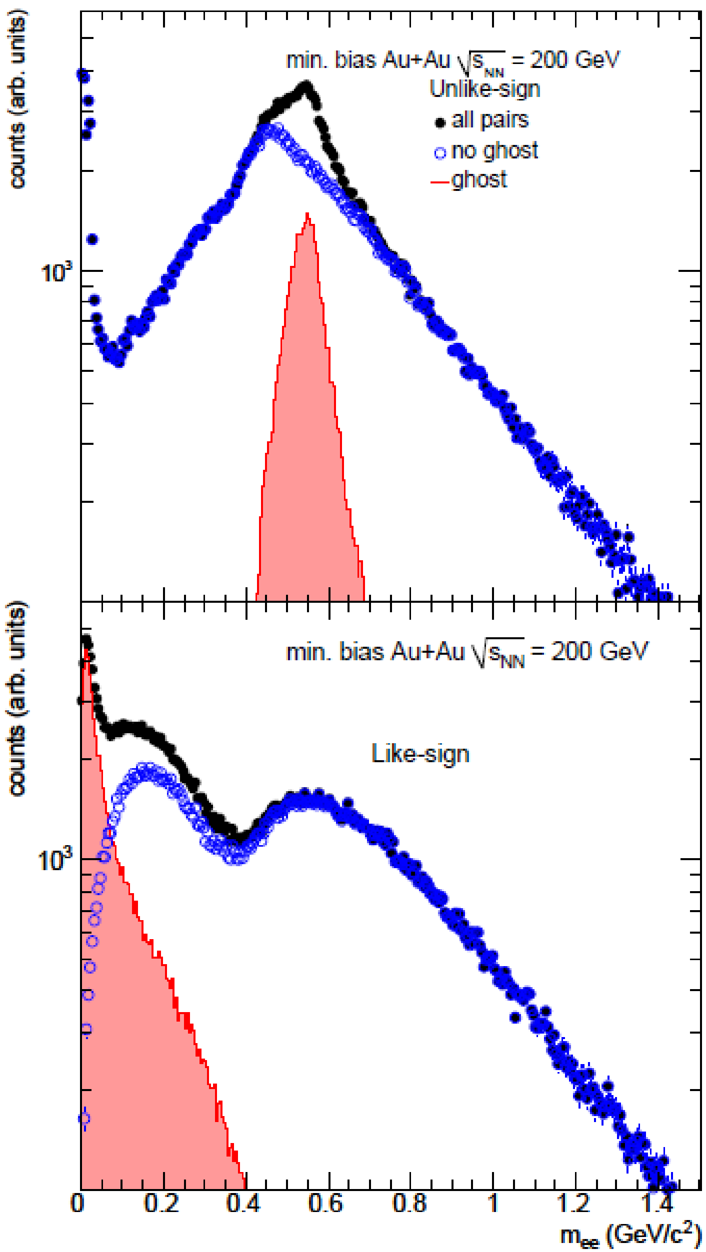
comprehensive results of dilepton measurements at RHIC.

Background

- Type I: identified on a pair-by-pair basis:
  - Overlapping hits in the detectors (mostly RICH)
  - Photon conversions
- Type II: cannot be identified on pair-by-pair basis → removed statistically
  - Combinatorial B^{comb} all combinations where the origin of the two electrons is totally uncorrelated
  - Correlated B^{corr}
    - Cross pairs: Two pairs in the final state of a meson
    - Jet pairs: Two hadrons within the same jet or in back-to-back jets, decay into electron pairs

Overlapping pairs



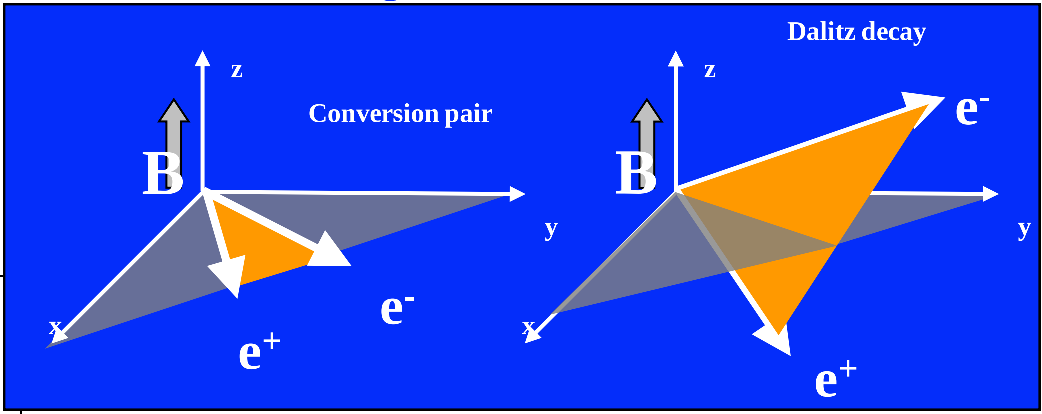
- when a pion points to the same ring as an electron, it is associated to the same ring, therefore considered an electron
  This happens for a typical values of opening angle (different for like and unlike) which folded with the average momentum of the electron corresponds to a particular invariant mass (different for like and unlike)
  → cut: requested minimum distance between the rings (~1 ring diameter)
- Cut applied as event cut
  - Real events: discarded and never reused
  - Mixed events: regenerated to avoid topology dependence

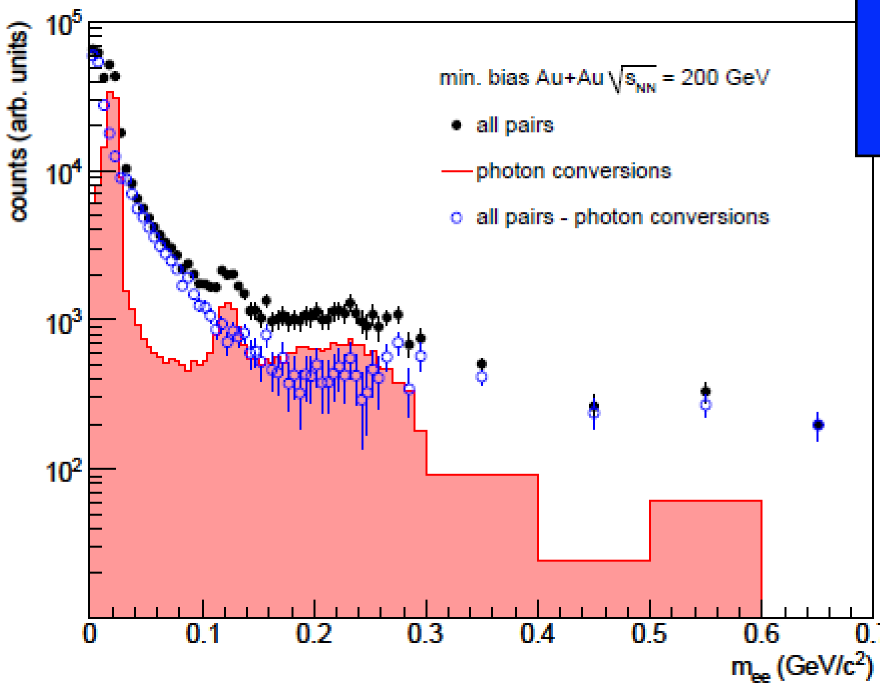
Photon conversion rejection

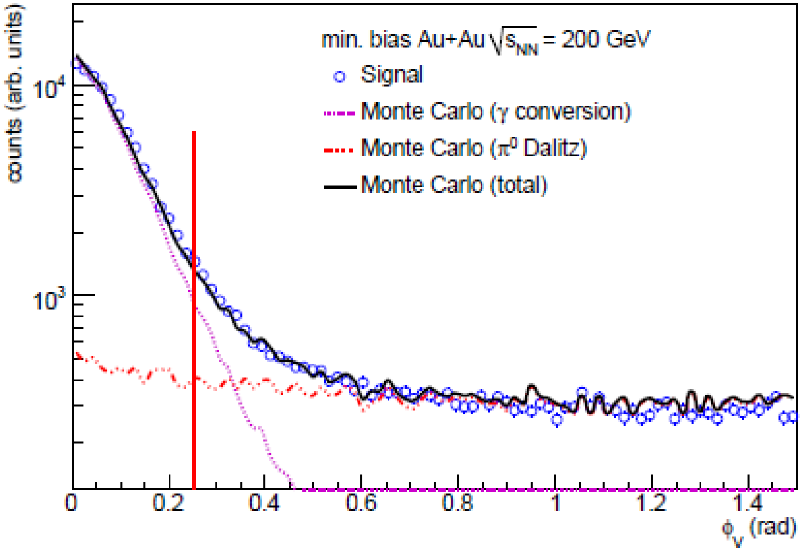
- artifact of PHENIX tracking
  - assume that all tracks originate from the vertex
  - off vertex tracks → wrong momentum vector

→ conversions are reconstructed with m≠0 (m~r)

- conversions "open" in a plane perpendicular to the magnetic field





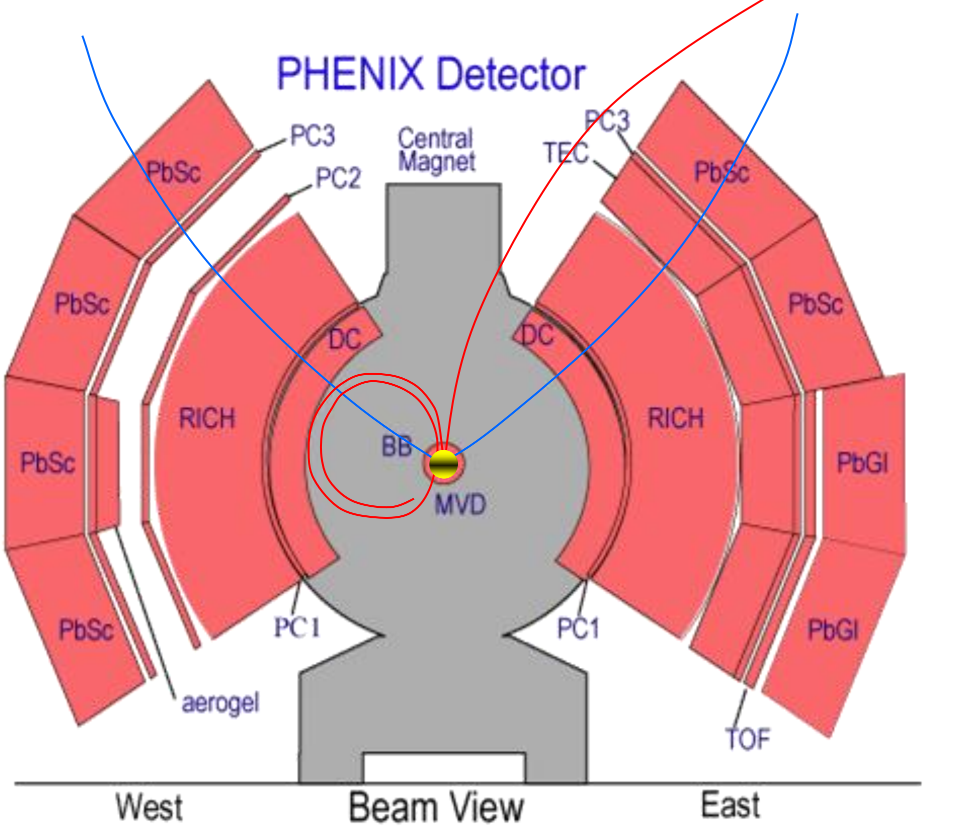


Low-mass e^+e^- pairs: the problem

- **electrons/event in PHENIX**
  - $N_e = (dN/d\eta)\pi^0 * (BR+CONV) * acc * f(p_T>0.2GeV)$
    350 (0.012+0.02) 0.5*0.7 0.32 = 1.3
- **combinatorial background pairs/event**
  - $B = ½ * ½N_e^2e^{-N} = 0.1$
- **expected signal pairs/event (m>0.2GeV, p_T>0.2 GeV)**
  - $S = 4.2*10^{-4}$

→**signal/background**
  - **as small as 1/ few hundred**
  - **depends on mass**
- **what can we do to reduce the combinatorial background? where does it come from?**

Conversion/Dalitz rejection?



- typically only one “leg” of the pair is in the acceptance
  - acceptance holes
  - “soft” tracks curl up in the magnetic field
- only (!) solution
  - catch electrons before they are lost
  - need new detector and modification of magnetic field

Consequences of poor S/B^{comb}

- how is the signal obtained?
  - unlike-sign pairs: F
  - combinatorial background: B (like-sign pairs or event mixing)
  - → $S = F - B$
- statistical error of S
  - depends on magnitude of B, not S
  - $\Delta S \approx \sqrt{2B}$ (for $S \ll B$)
- “background free equivalent” signal S_{eq}
  - signal with same relative error in a situation with zero background
  - $S_{eq} = S * S/2B$
  - example: $S = 10^4$ pairs with $S/B = 1/250$ → $S_{eq} = 20$
- systematic uncertainty of S
  - dominated by systematic uncertainty of B
  - example: event mixing with 0.25% precision (fantastic!)
    → ~60% systematic uncertainty of S (for $S/B = 1/250$)

Type II background

METHOD 1

- **Combinatorial background: event mixing**
  - **Like and Unlike-sign pairs taking electons from different events**
  - **Normalize like-sign background to like-sign foreground in a region in $(m,p_T)$where they agree**
  - **Normalize unlike-sign background to $2\sqrt{N_{++}N_{--}}$**
- **Correlated background: simulations**
  - **Cross pairs: EXODUS**
  - **Jet pairs: PYTHIA**
  - **Normalize like-sign background to like-sign foreground**
  - **Normalize unlike-sign background in the same way**

ADVANTAGE

- **Great statistics (much larger than foreground)**

DISADVANTAGE

- **Assume simulation shape**
- **Need independent normalization**

Type II background

METHOD 2

- If $dN_{like} = dN_{unlike} \rightarrow S_{+-} = N_{+-} - 2\sqrt{N_{++}N_{--}}$
- In PHENIX $dN_{like} \neq dN_{unlike}$
  - But unlike-sign background $B_{+-} = 2\sqrt{N_{++}N_{--}}$ can be corrected by acceptance difference

$$S_{+-} = N_{+-} - 2\sqrt{N_{++}N_{--}} \cdot \frac{B_{+-}^{\text{comb}}}{2\sqrt{B_{++}^{\text{comb}} \cdot B_{--}^{\text{comb}}}}$$

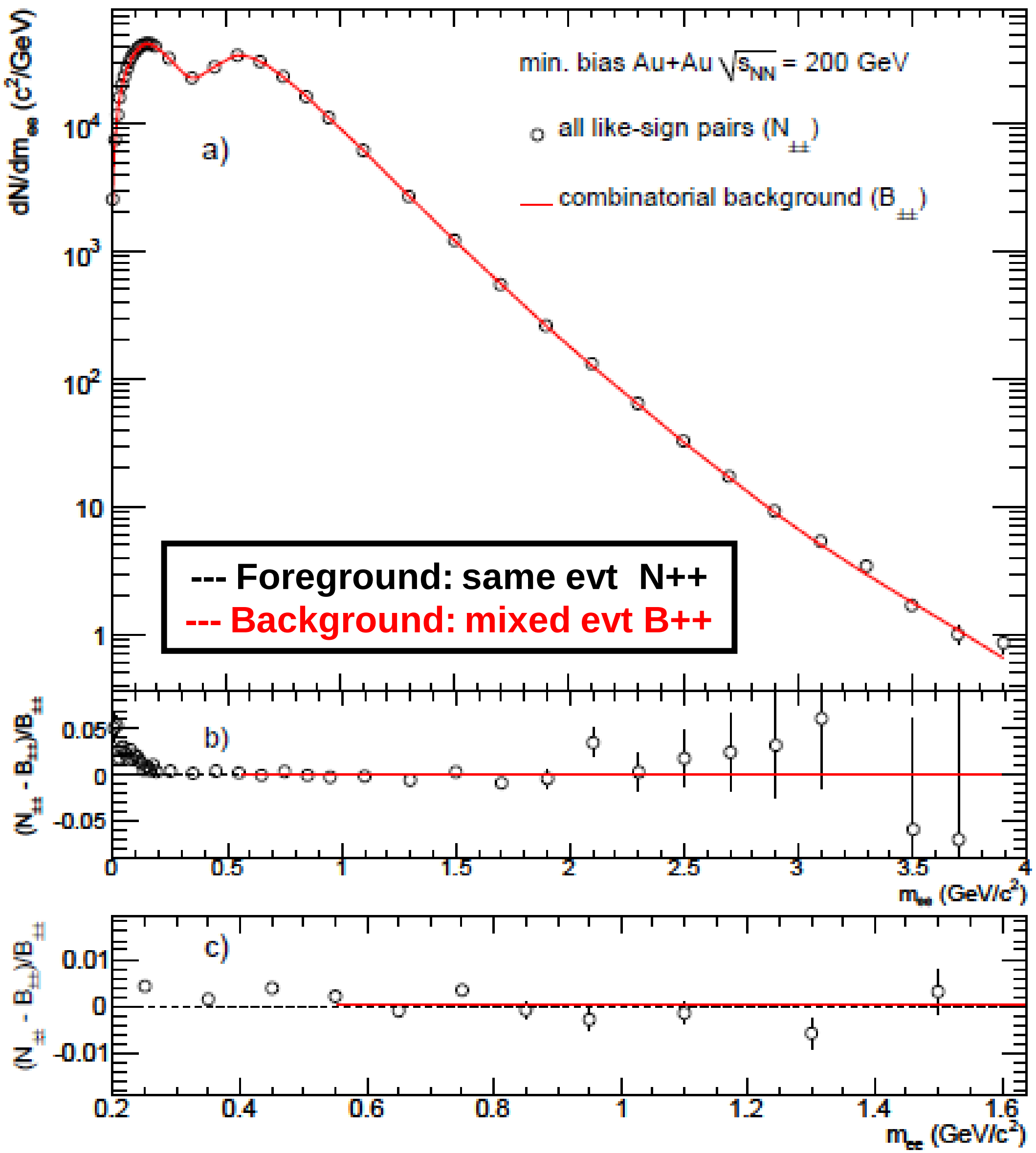
ADVANTAGE

- This method measures ALL type II background simultaneously
- only assumptions needed:
  - dN_{like} measures only background
  - Background symmetric in like and unlike

DISADVANTAGE

- Poor statistics (similar to foreground)

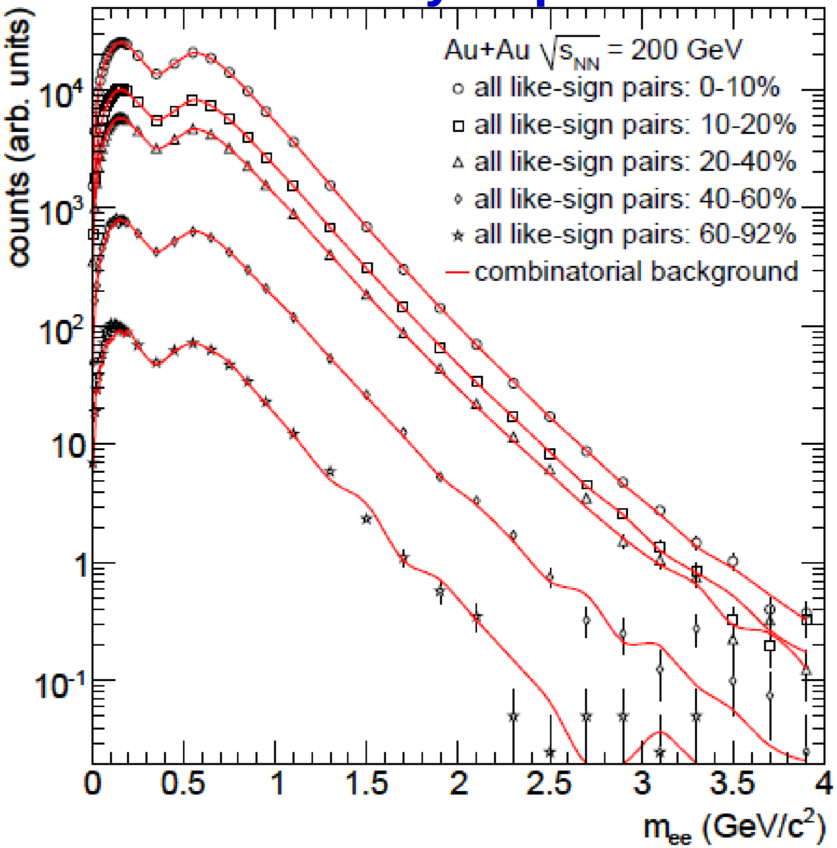
Combinatorial Background shape



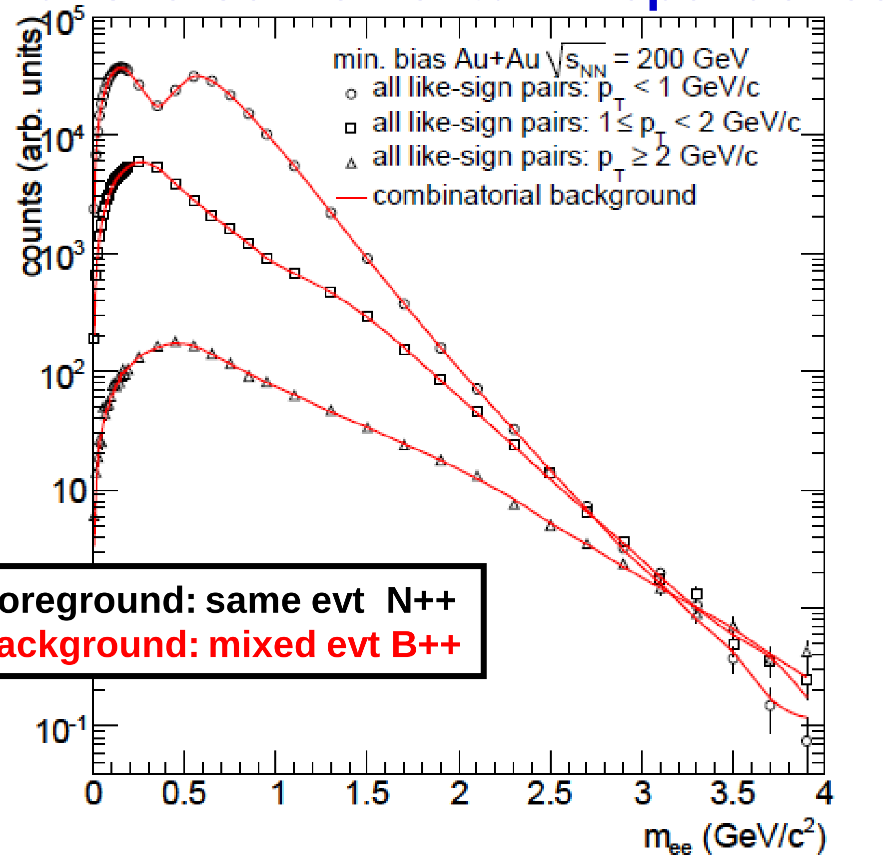
- Shape determined with event mixing
  - Excellent agreements for like-sign pairs
- Normalization of mixed pairs
  - Small correlated background at low masses
  - normalize B_{++} and B_{--} to N_{++} and N_{--} for $m_{ee} > 0.7$ GeV/c^2
  - Normalize mixed B_{+-} pairs to $N_{+-} = 2\sqrt{N_{++}N_{--}}$
  - Subtract correlated background
- Systematic uncertainties
  - statistics of N_{++} and N_{--} : 0.12%
  - different pair cuts in like and unlike sign: 0.2 %

Differential Combinatorial Background

Centrality Dependence



Transverse Momentum Dependence



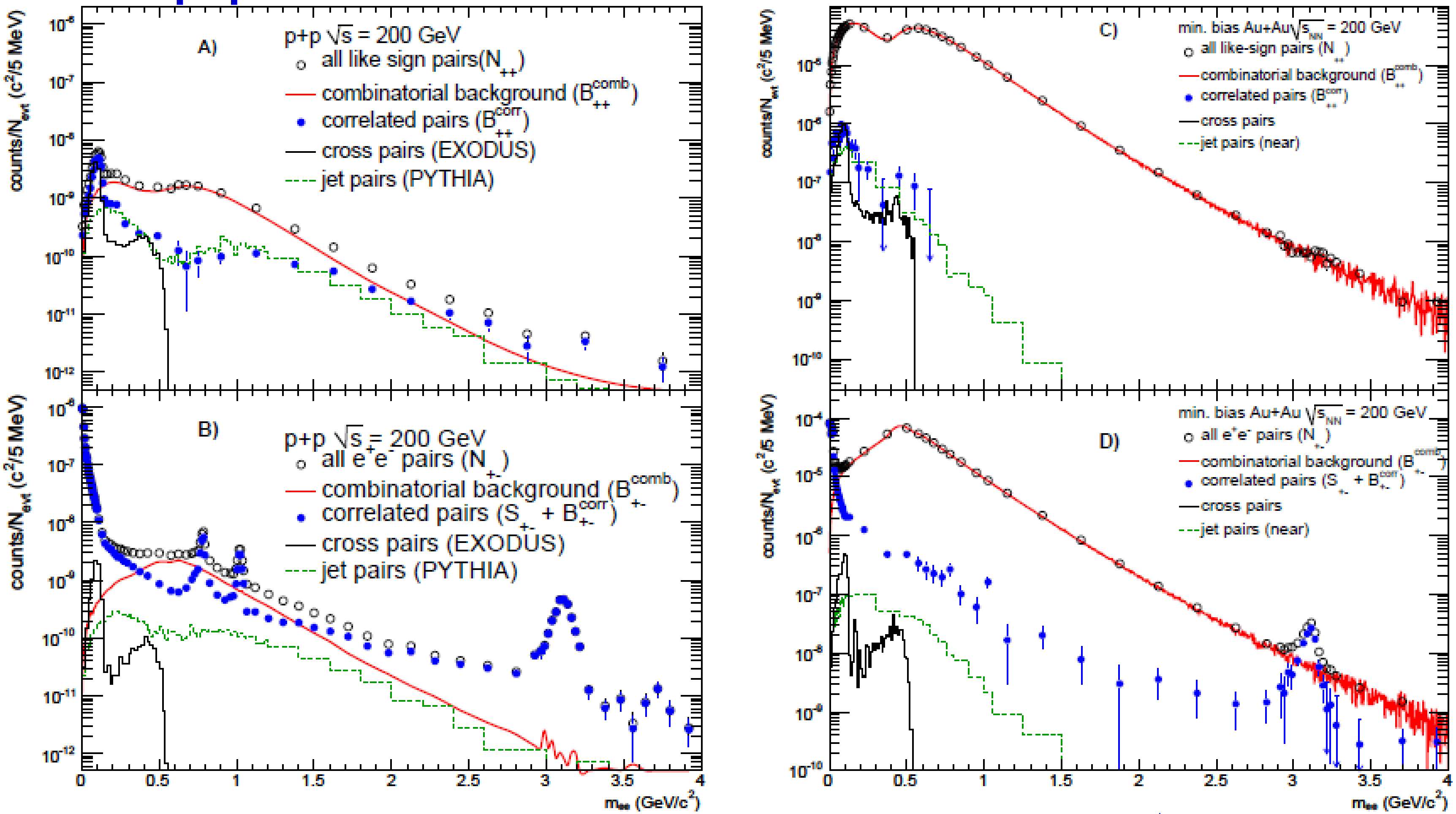
--- Foreground: same evt N++

--- Background: mixed evt B++

Centrality	p_0	χ^2/NDF	χ^2 test	p-value	max dev.
0-10%	$6.3 \pm 8.8 \times 10^{-4}$	30.2/19	1.05	0.25	0.0014
10-20%	$-9.4 \pm 1.4 \times 10^{-4}$	18.6/19	0.97	0.61	0.0018
20-40%	$-2.4 \pm 1.8 \times 10^{-3}$	18.7/19	1.02	0.40	0.0034
40-60%	$-8.5 \pm 4.9 \times 10^{-3}$	21.9/19	1.65	0.02	0.0071
60-92%	$-1.8 \pm 1.6 \times 10^{-2}$	21.5/14	1.51	0.04	0.0321
00-92%	$2.6 \pm 6.3 \times 10^{-4}$	27.6/19	0.92	0.83	0.0010
$p_T < 1$ GeV/c	$9.2 \pm 5.1 \times 10^{-4}$	18.9/18	0.95	0.73	0.0011
$1 < p_T < 2$ GeV/c	$-3.4 \pm 1.6 \times 10^{-3}$	27.9/18	0.91	0.84	0.0029
$p_T > 2$ GeV/c	$-9.6 \pm 5.4 \times 10^{-3}$	15.2/18	0.97	0.63	0.0038

Combinatorial and Correlated Background

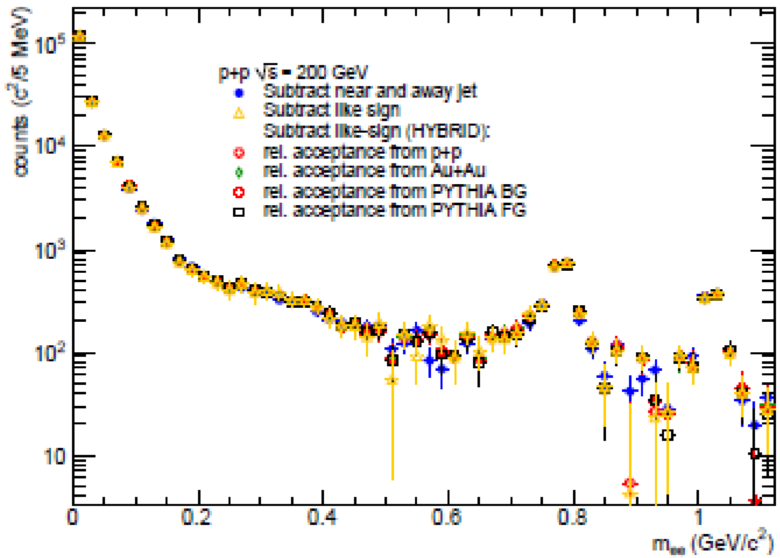
p+p **Au+Au**

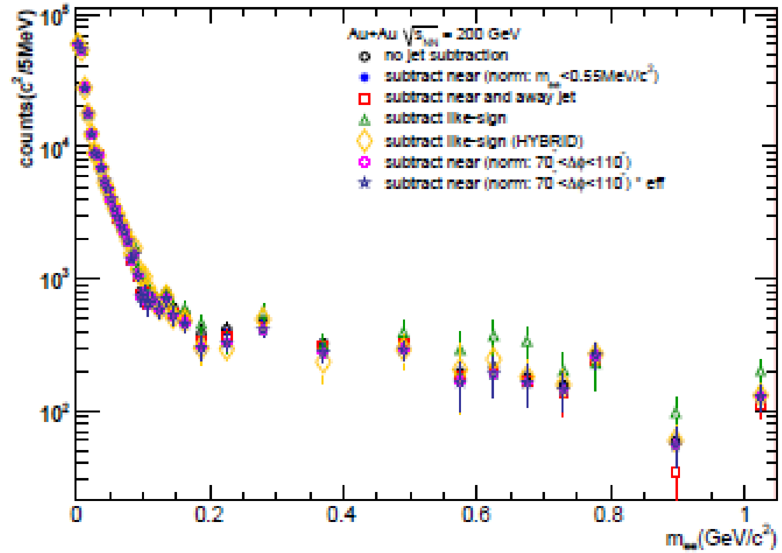


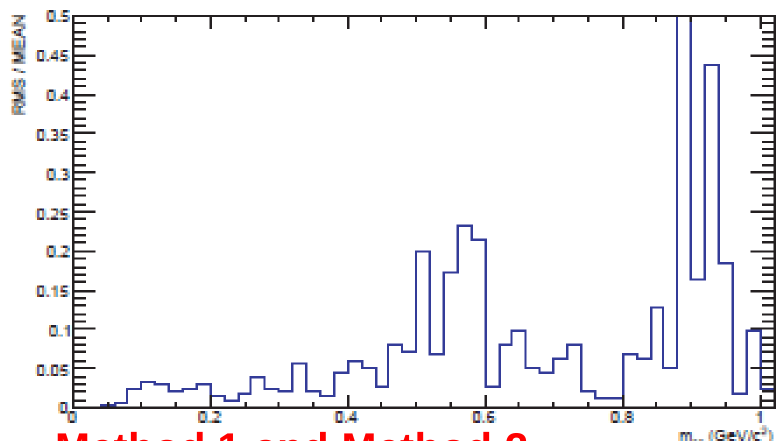
- **Combinatorial Background** from mixed events normalized to $2\sqrt{N_{++}N_{--}}$
- **Cross pairs** simulated with decay generator EXODUS
- **Jet pairs** simulated with PYTHIA
- normalized to like sign data and use same normalization for unlike-sign

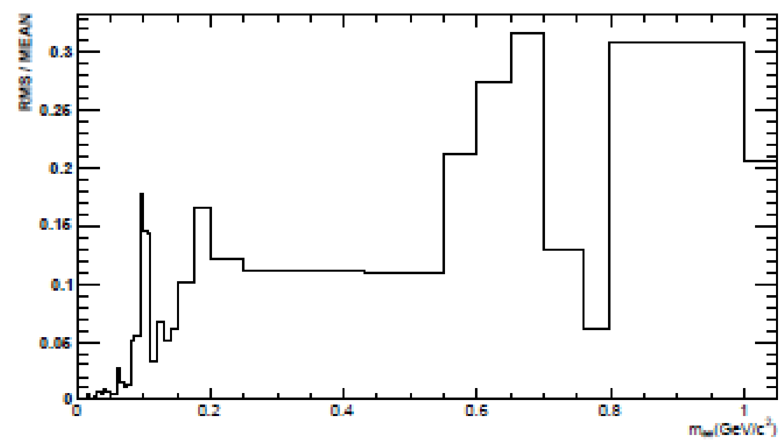
Uncertainty of Background Subtraction

p+p | **Au+Au**





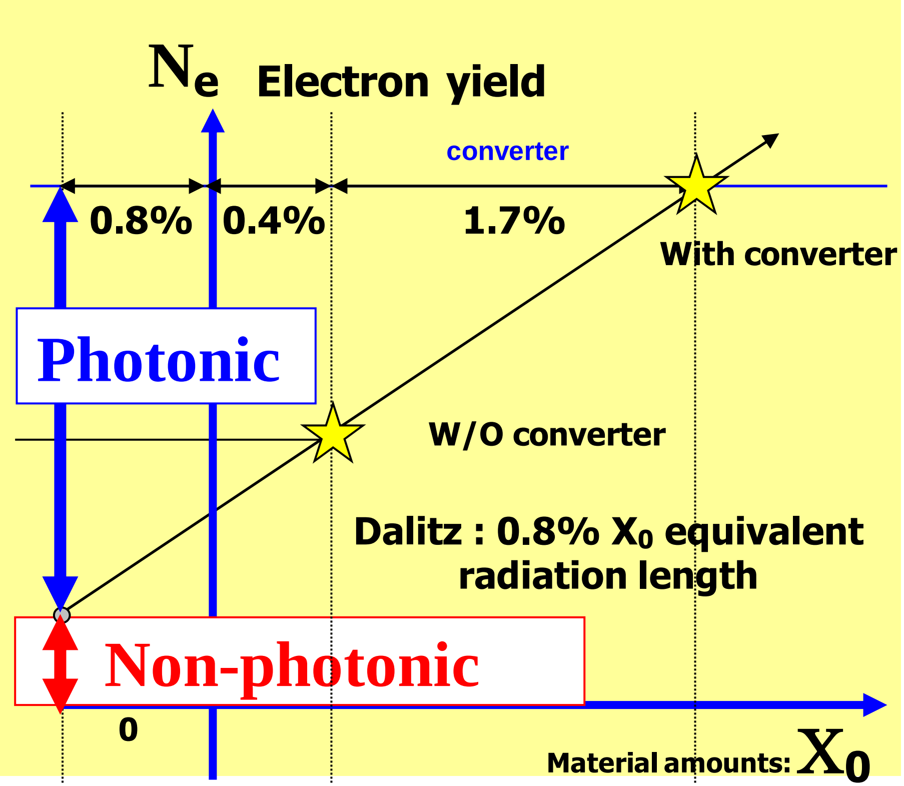




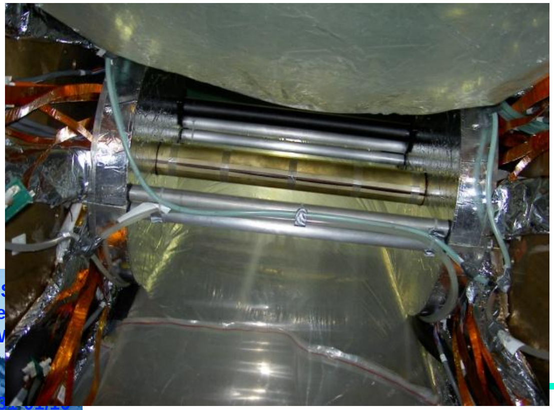
- Method 1 and Method 2
- Variations of the two method
- RMS → Systematic Uncertainty

Cross check Converter Method

- We know precise radiation length (X_0) of each detector material
- The photonic electron yield can be measured by increase of additional material (photon converter was installed)
- The non-photonic electron yield does not increase
- Photonic single electron: x 2.3
- Inclusive single electron :x 1.6
- Combinatorial pairs :x 2.5



Photon Converter (Brass: 1.7% X_0)



The raw subtracted spectrum

Same analysis on data sample with additional conversion material

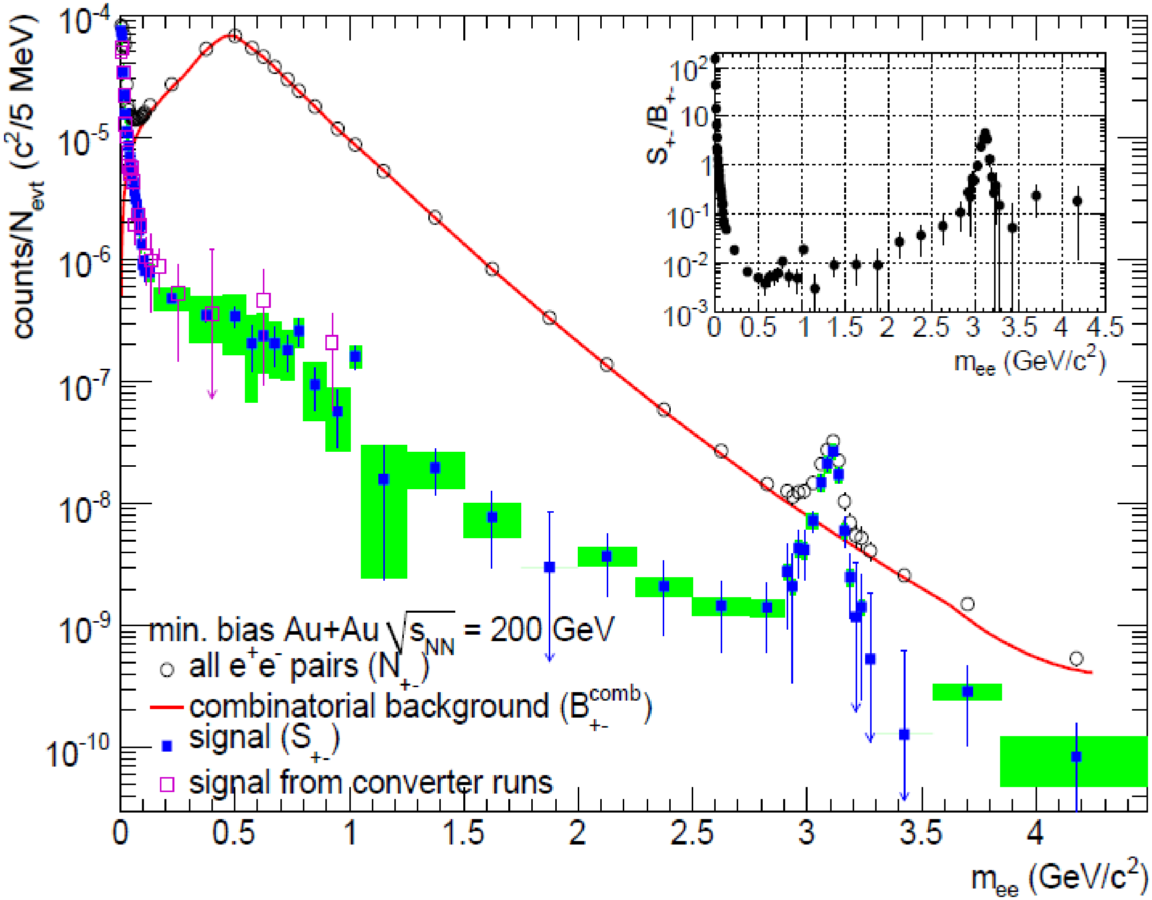
→Combinatorial background increased by 2.5

Good agreement within statistical error

$$\sigma_{signal}/\text{signal} = \boxed{\sigma_{BG}/BG} * \boxed{BG/\text{signal}}$$

0.25%

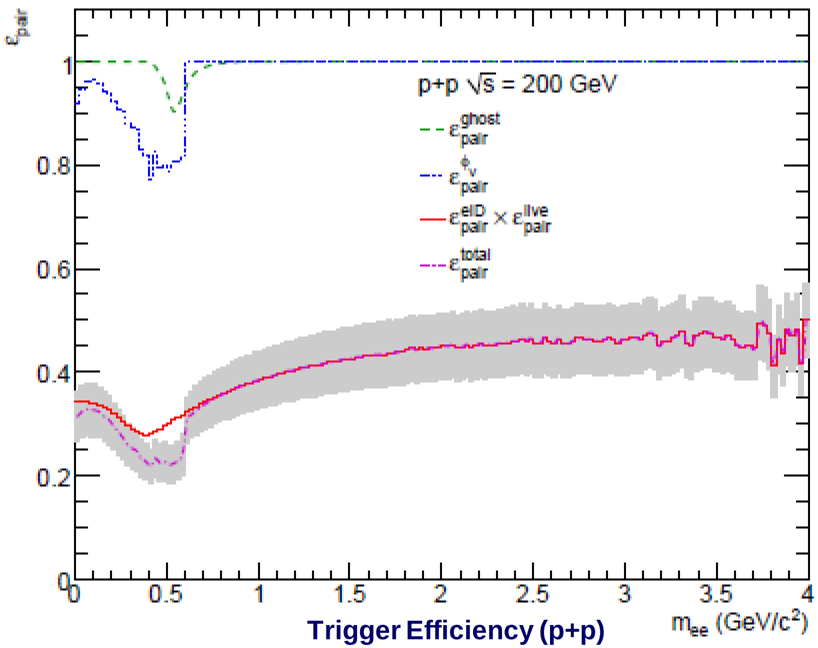
large!!!



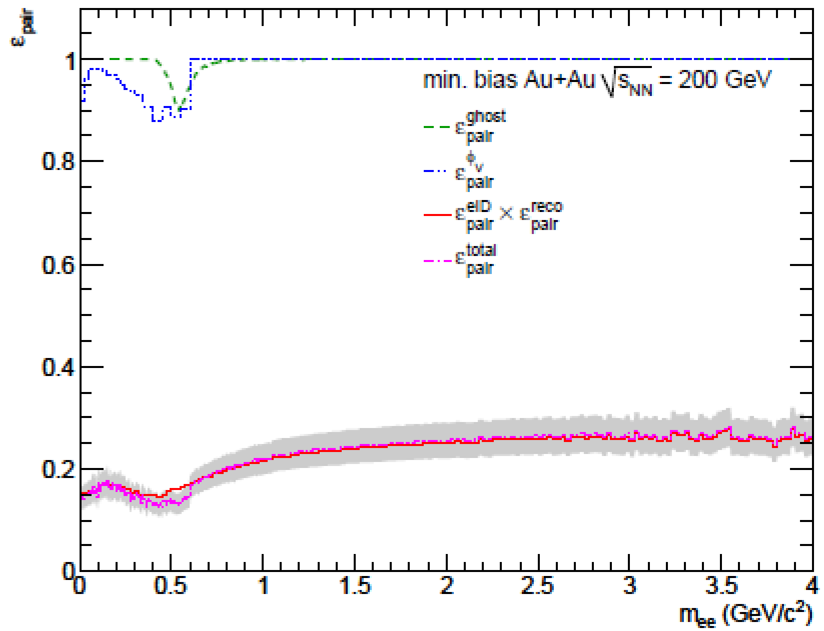
From the agreement converter/non-converter and the decreased S/B ratio
scale error = 0.15±0.51%
(consistent with the 0.25% error we assigned)

Efficiency Correction

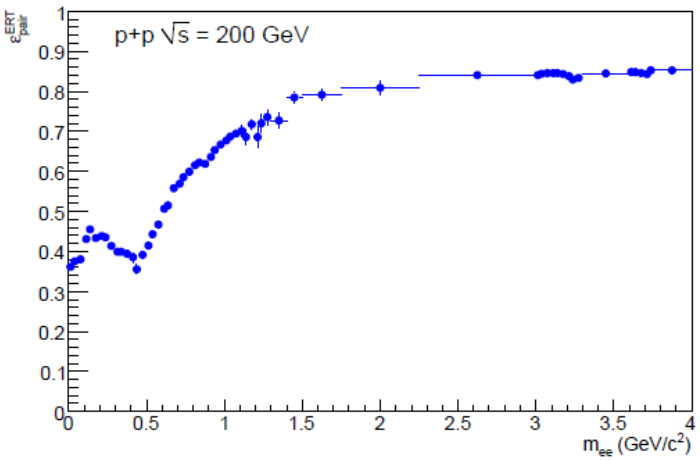
p+p



Au+Au



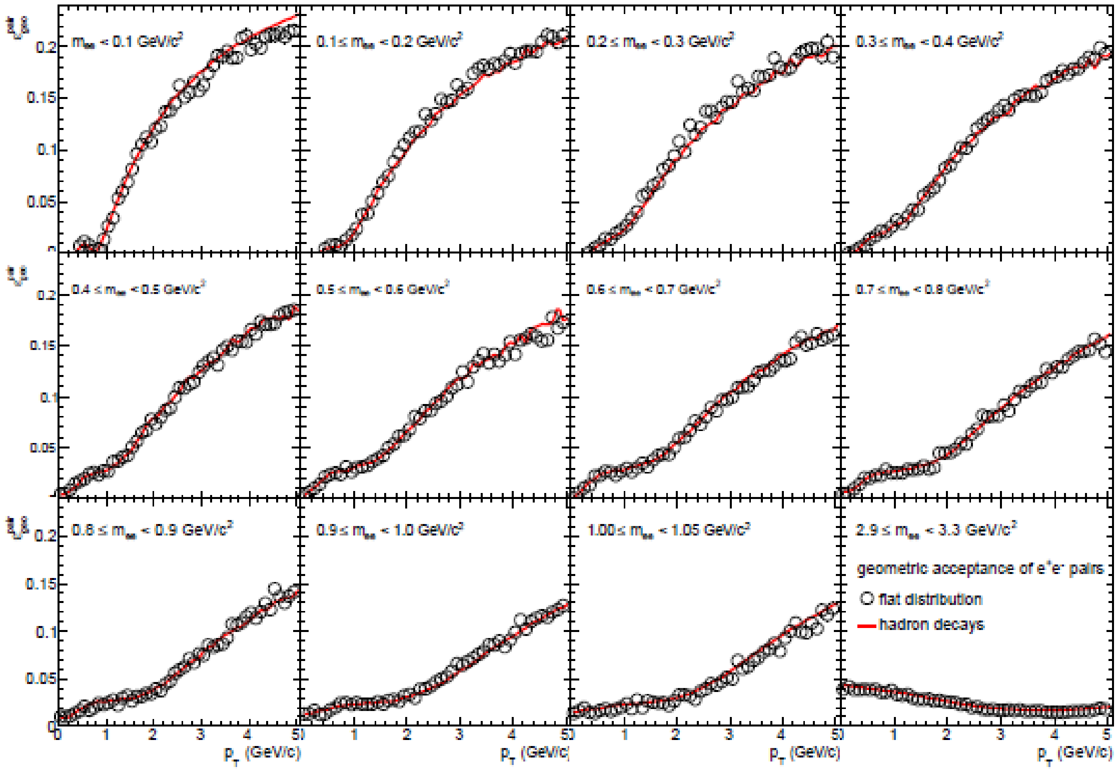
Trigger Efficiency (p+p)

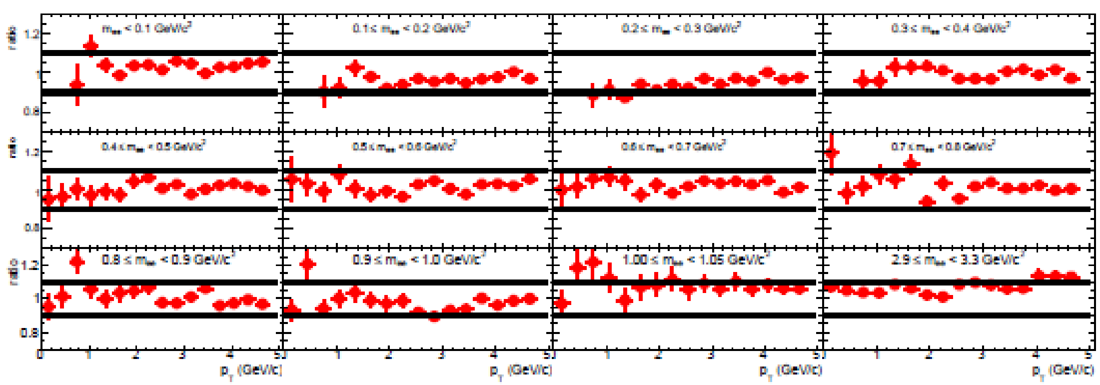


Efficiency Correction:

- Derived from single electron efficiency
- Include detector dead areas
- Include pair cuts
- Same shape for p+p and Au+Au
- p+p further corrected for trigger efficiency

Acceptance Correction





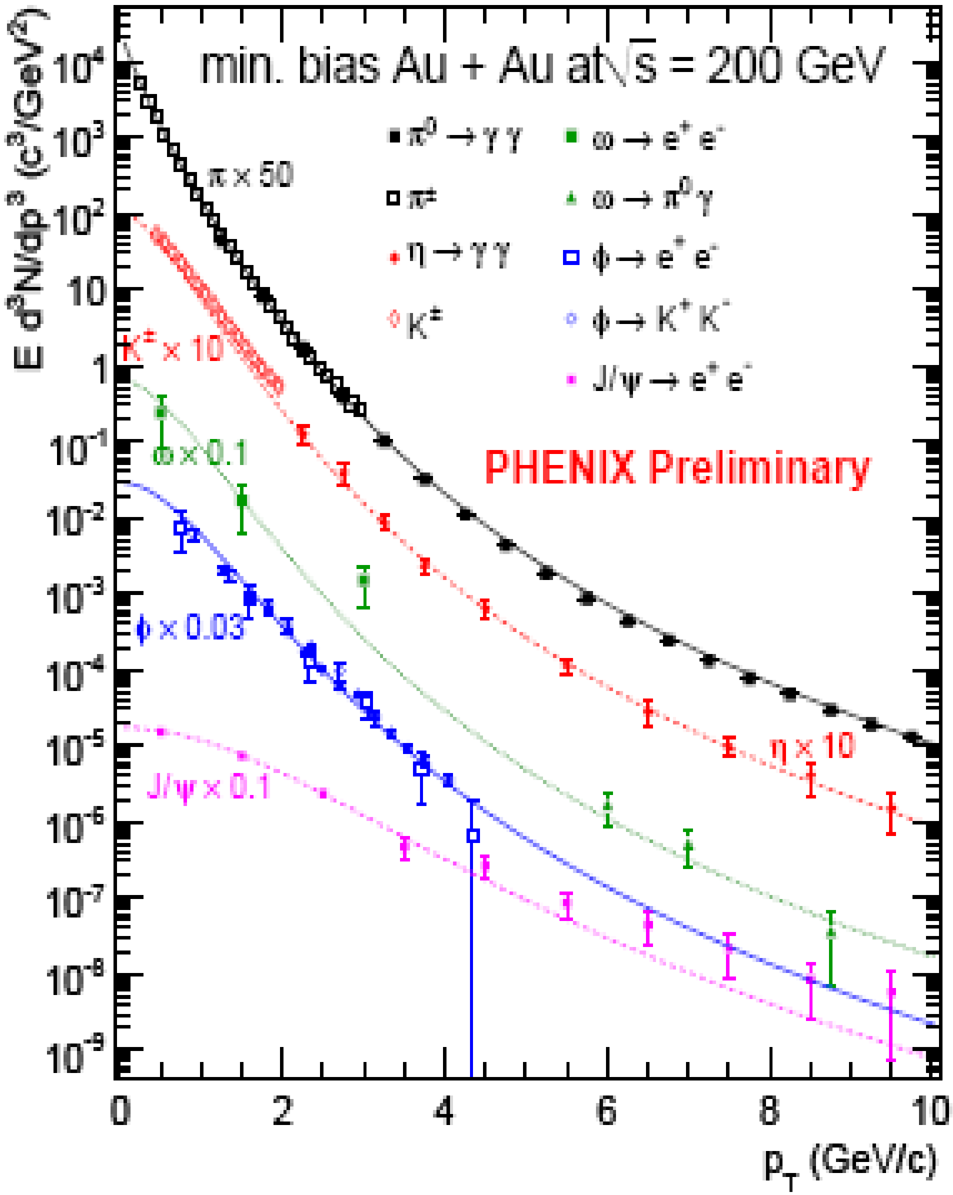
Acceptance Correction:

- Derived from single electron acceptance
- Compare
  - Hadron decays (full cocktail)
  - Flat distribution

in different mass regions as function of p_T

- Difference within ~10%

Hadronic Cocktail Measurement



- **Parameterization of PHENIX $\pi^\pm$,π^0 data π^0 = $(\pi^+ + \pi^-)/2$**

$$E\frac{d^3\sigma}{d^3p} = \frac{A}{\left(\exp(-ap_T - bp_T^2) + p_T/p_0\right)^n}$$

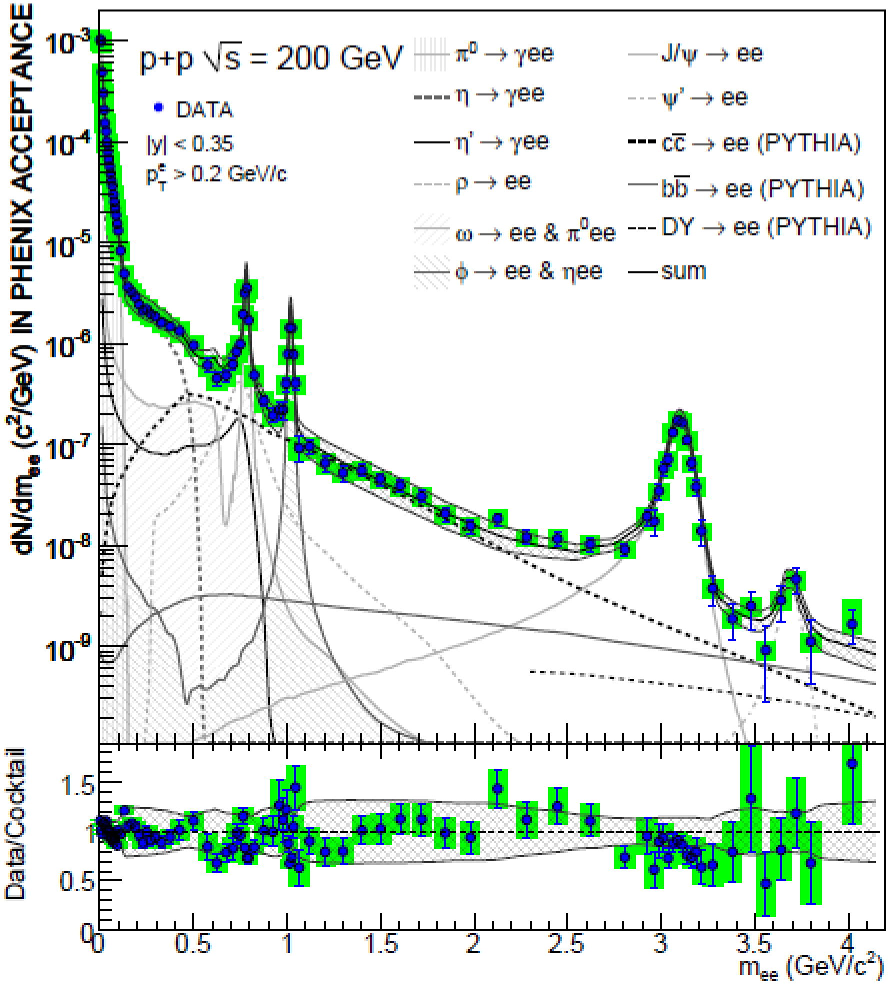
- **Other mesons:fit with m_T scaling of π^0 $p_T \rightarrow \sqrt{(p_T^2 + m_{meson}^2 - m_\pi^2)}$ fit the normalization constant**

→All mesons m_T scale!!!

- **Hadronic cocktail was well tuned to individually measured yield of mesons in PHENIX for both p+p and Au+Au collisions.**
- **Mass distributions from hadron decays are simulated by Monte Carlo.**
  - π^0, η, η', ω, ϕ, ρ, J/ψ, ψ'
- **Effects on real data are implemented**

PLB 670,313(2009)
arXiv:0912.0244

Cocktail Comparison p+p



- 2.25pb^{-1} of triggered p+p data
- Data absolutely normalized

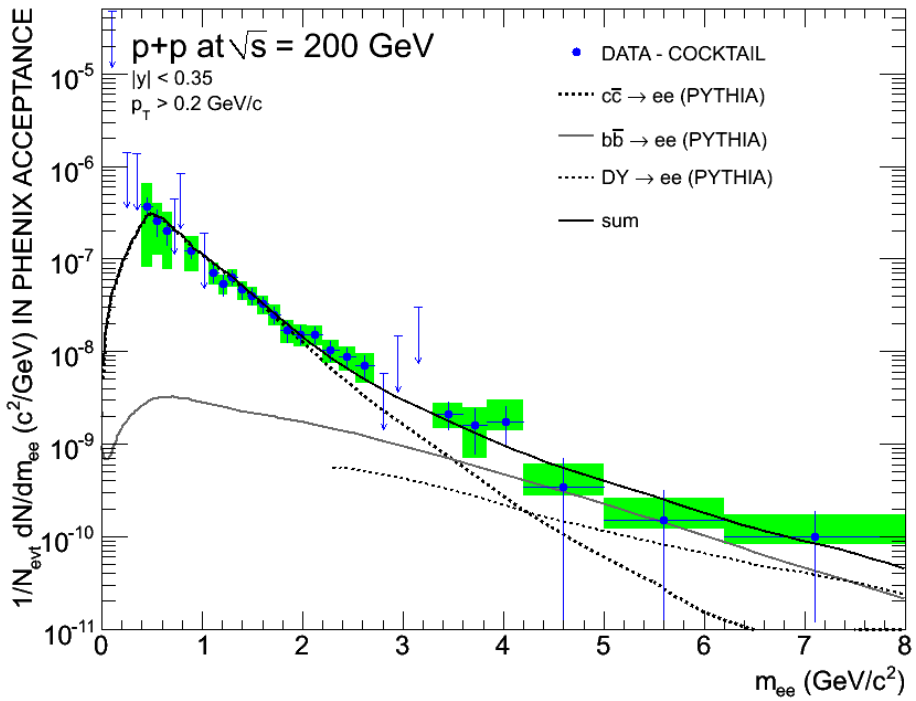
- Excellent agreement with Cocktail
- Filtered in PHENIX acceptance

Light hadron contributions subtracted

Heavy Quark Cross Sections:

- Charm: integration after cocktail subtraction
  $\sigma_{cc} = 544 \pm 39^{stat} \pm 142^{syst} \pm 200^{model}$ μb
- Simultaneous fit of charm and bottom:
  – $\sigma_{cc} = 518 \pm 47^{stat} \pm 135^{syst} \pm 190^{model}$ μb
  – $\sigma_{bb} = 3.9 \pm 2.4^{stat} +3/-2^{syst}$ μb
  - Charm cross section from single electron **measurement** **[PRL97, 252002 (2006)]:**
  – $\sigma_{cc} = 567 \pm 57 \pm 193$ μb

PLB 670,313(2009)



Charm and bottom cross sections

CHARM

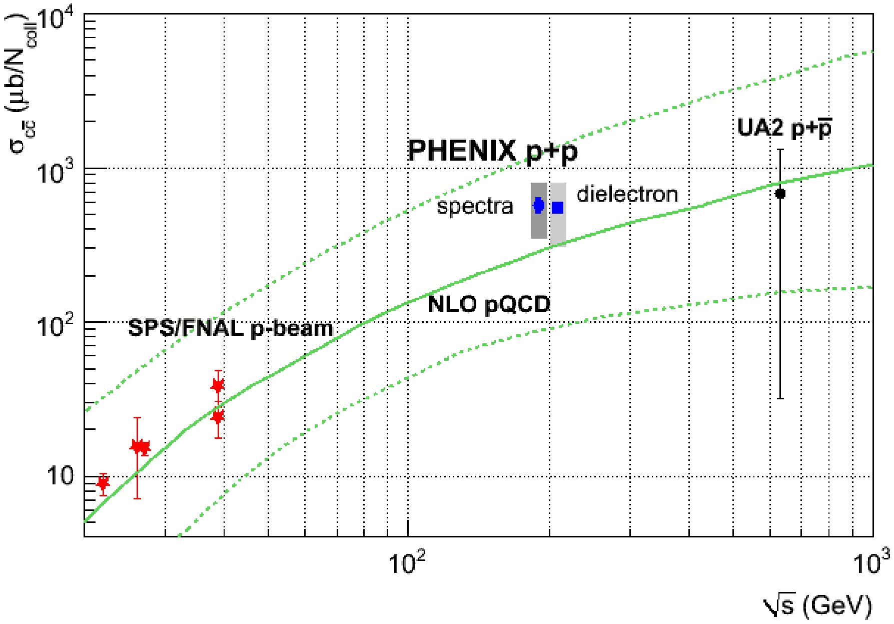
Dilepton measurement in agreement with single electron, single muon, and with FONLL (upper end)

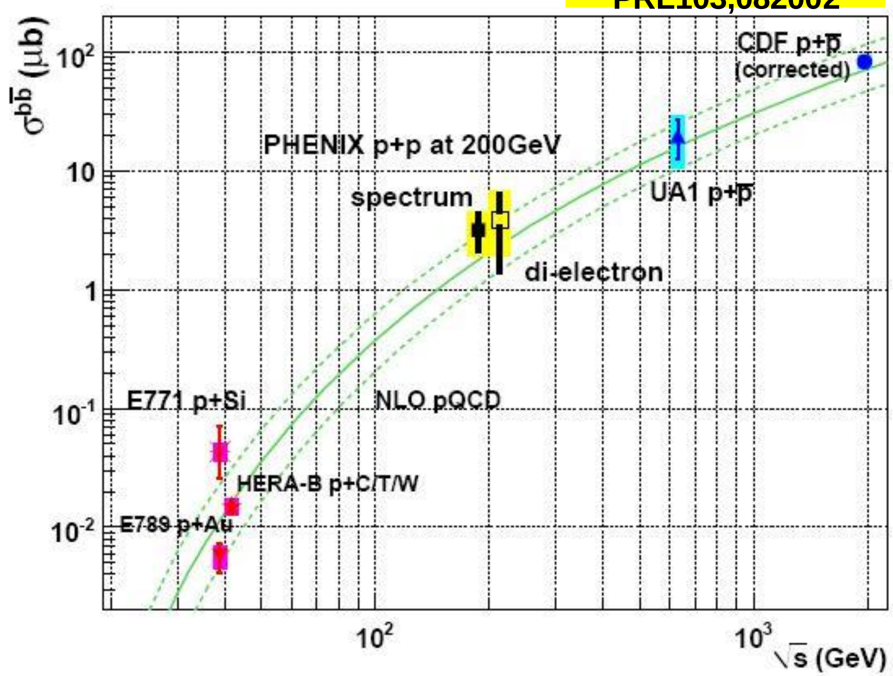
BOTTOM

Dilepton measurement in agreement with measurement from e-h correlation and with FONLL (upper end)

PLB670,313(2009)

PRL103,082002

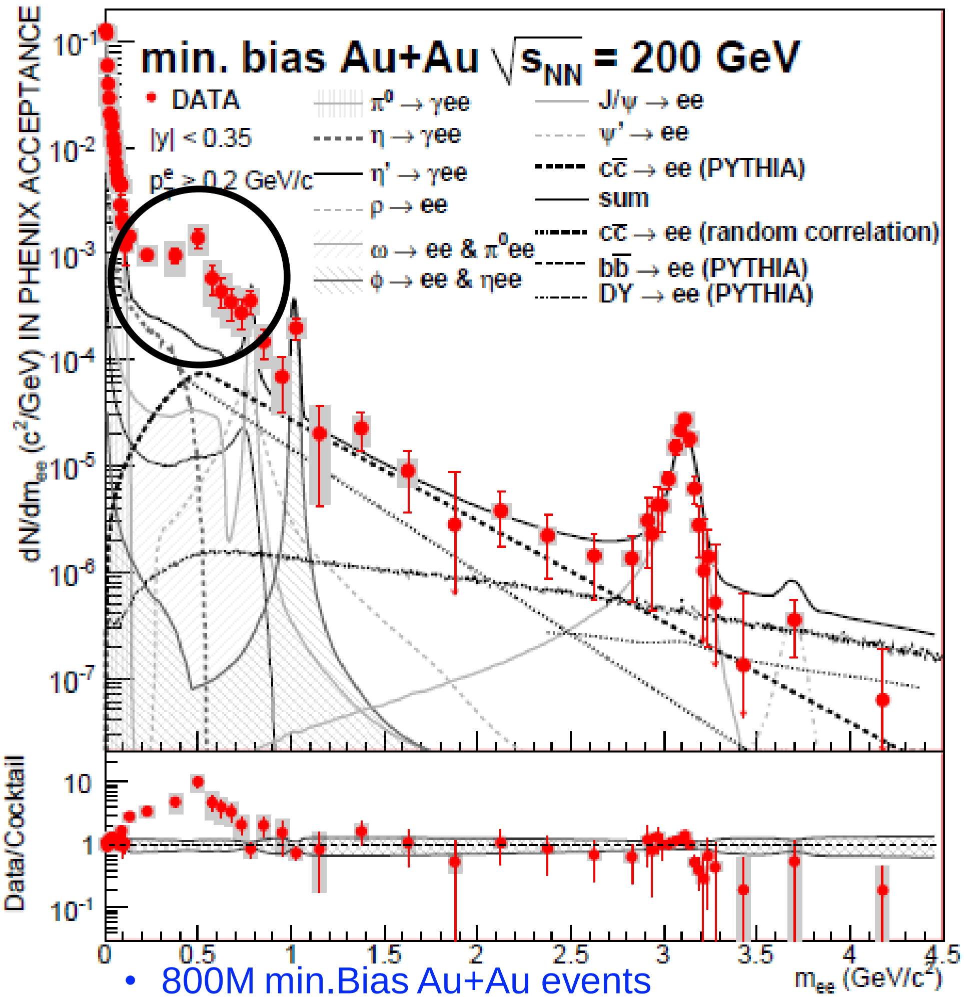




First measurements of bottom cross section at RHIC energies!

Cocktail Comparison Au+Au

arXiv:0912.0244



- 800M min.Bias Au+Au events
- Data absolutely normalized

- Light hadrons cocktail
- **Charm normalized N_{coll} x σ_{pp}**

Filtered in PHENIX acceptance

- **Low Mass Region:**
  large enhancement 150 <m_{ee}<750 MeV
  $4.7 \pm 0.4^{stat} \pm 1.5^{syst} \pm 0.9^{model}$

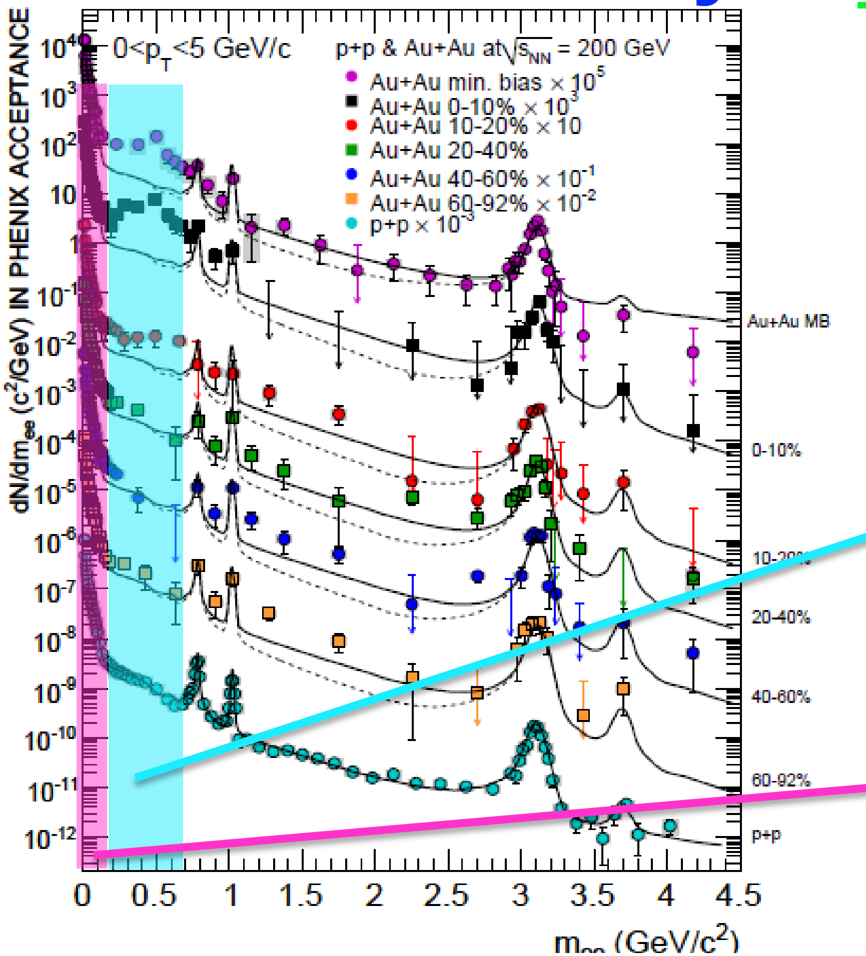
- **Intermediate Mass Region:**
  dominated by charm (N_{coll} x σ_{cc})
  - **PYTHIA**
  - **Random cc correlation**

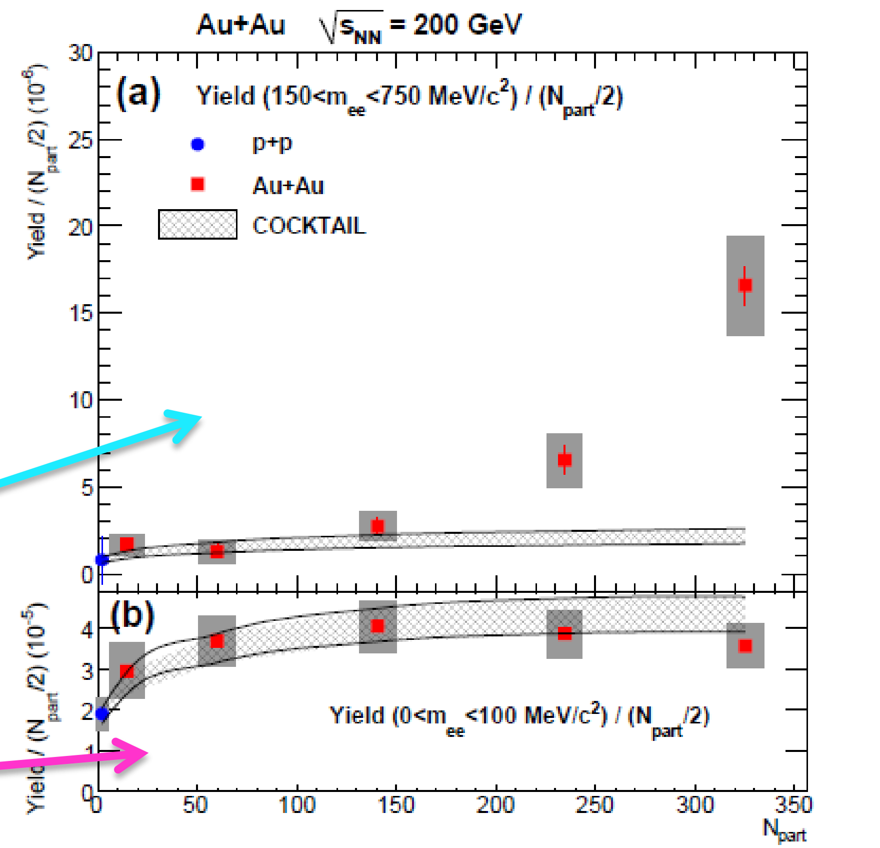
- **Single electron measurement**
  - **High p_T suppression**
  - **Flow**

  →Expected modifications in the pair invariant mass
  → random cc correlation?
  →Room for thermal contribution?

arXiv:0912.0244

Centrality Dependence LMR





arXiv:0912.0244

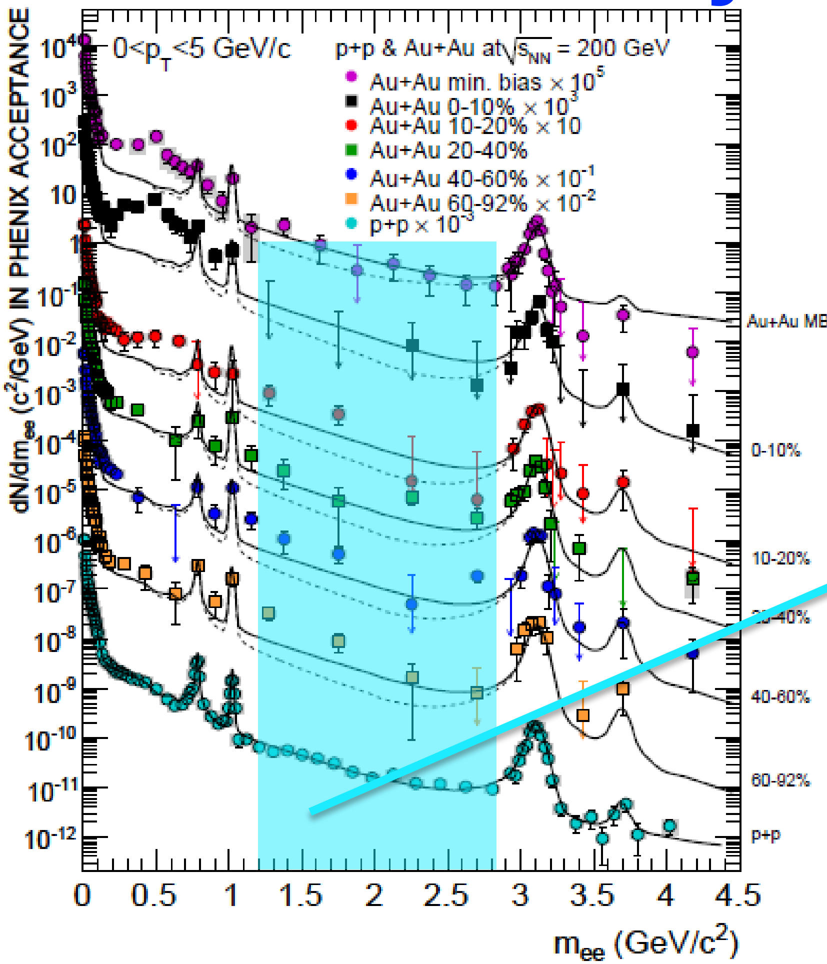
Centrality	Enhancement (±stat ±syst ±model)
00-10 %	7.6 ± 0.5 ± 1.5 ± 1.5
10-20 %	3.2 ± 0.4 ± 0.1 ± 0.6
20-40 %	1.4 ± 1.3 ± 0.02 ± 0.3
40-60 %	0.8 ± 0.3 ± 0.03 ± 0.2
60-92 %	1.5 ± 0.3 ± 0.001 ± 0.3
MB	4.7 ± 0.4 ± 1.5 ± 0.9

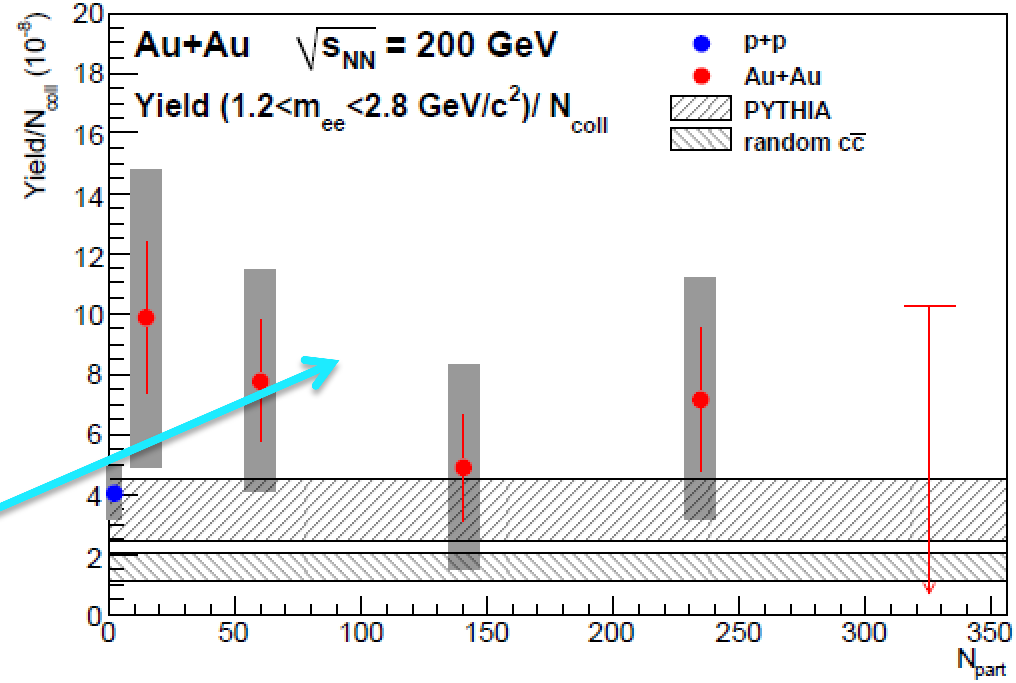
- **π^0 region:**
consistent with cocktail
- **Low Mass Region:**
yield increases faster than proportional to N_{part}

→ enhancement from binary annihilation (ππ or qq) ?

arXiv:0912.0244

Centrality Dependence IMR



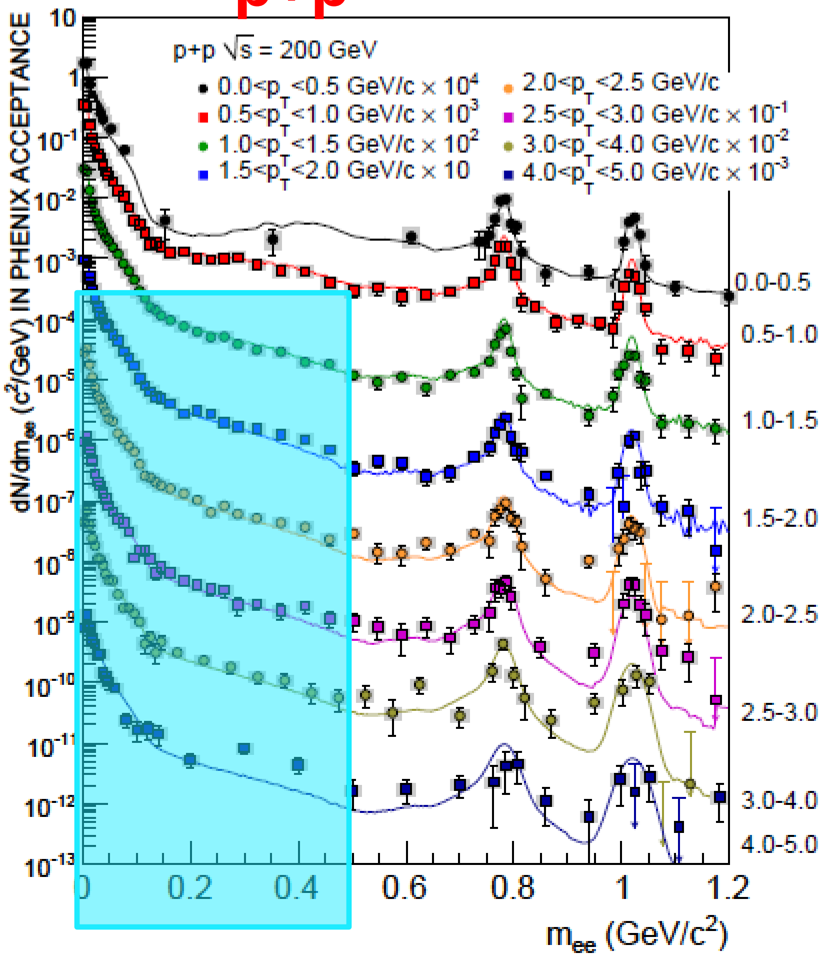


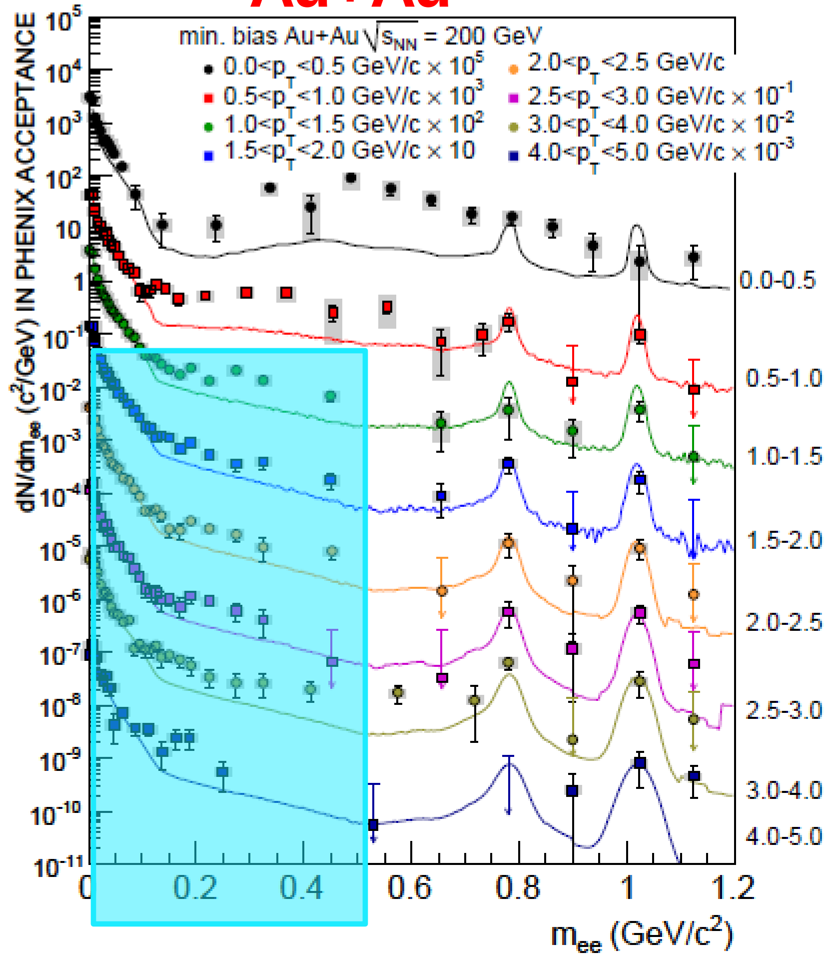
arXiv:0912.0244

- **charm is a hard probe**
  - **total yield follows binary scaling (known from single $e^{\pm}$)**
  - **intermediate mass yield shows the same scaling**

Momentum Dependence

arXiv:0912.0244





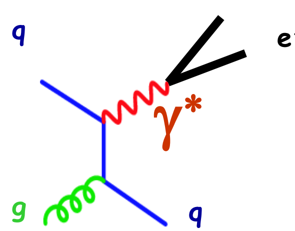
- p+p in agreement with cocktail
- Au+Au low mass enhancement concentrated at low p_T

LMR I: Virtual Photons

- Any source of real γ can emit γ* with very low mass.
- If the Q^2 (=m^2) of virtual photon is sufficiently small, the source strength should be the same
- The ratio of real photon and quasi-real photon can be calculated by QED

→ Real photon yield can be measured from virtual photon yield, which is observed as low mass e^+e^- pairs

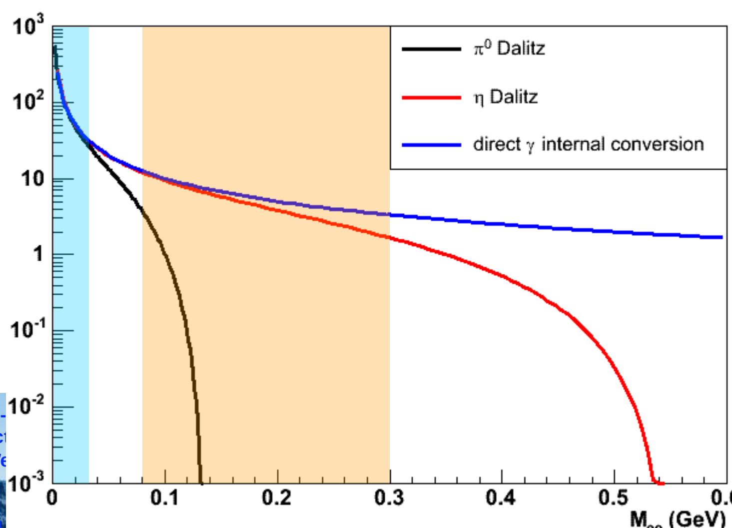
$$\frac{\gamma_{direct}}{\gamma_{inclusive}} = \frac{\gamma^*_{direct}}{\gamma^*_{inclusive}}$$



Kroll-Wada formula

$$\frac{d^2N}{dM_{ee}dN_\gamma} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{M_{ee}^2}}\left(1+\frac{2m_e^2}{M_{ee}^2}\right)\frac{1}{M_{ee}}S$$

S : Process dependent factor



- Case of Hadrons

$$S = \left|F\left(M_{ee}^2\right)\right|^2\left(1-\frac{M_{ee}^2}{M_{hadron}^2}\right)^3$$

  - Obviously $S = 0$ at $M_{ee} > M_{hadron}$

- Case of γ*
  - If $p_T^2 >> M_{ee}^2$

$$S = 1$$

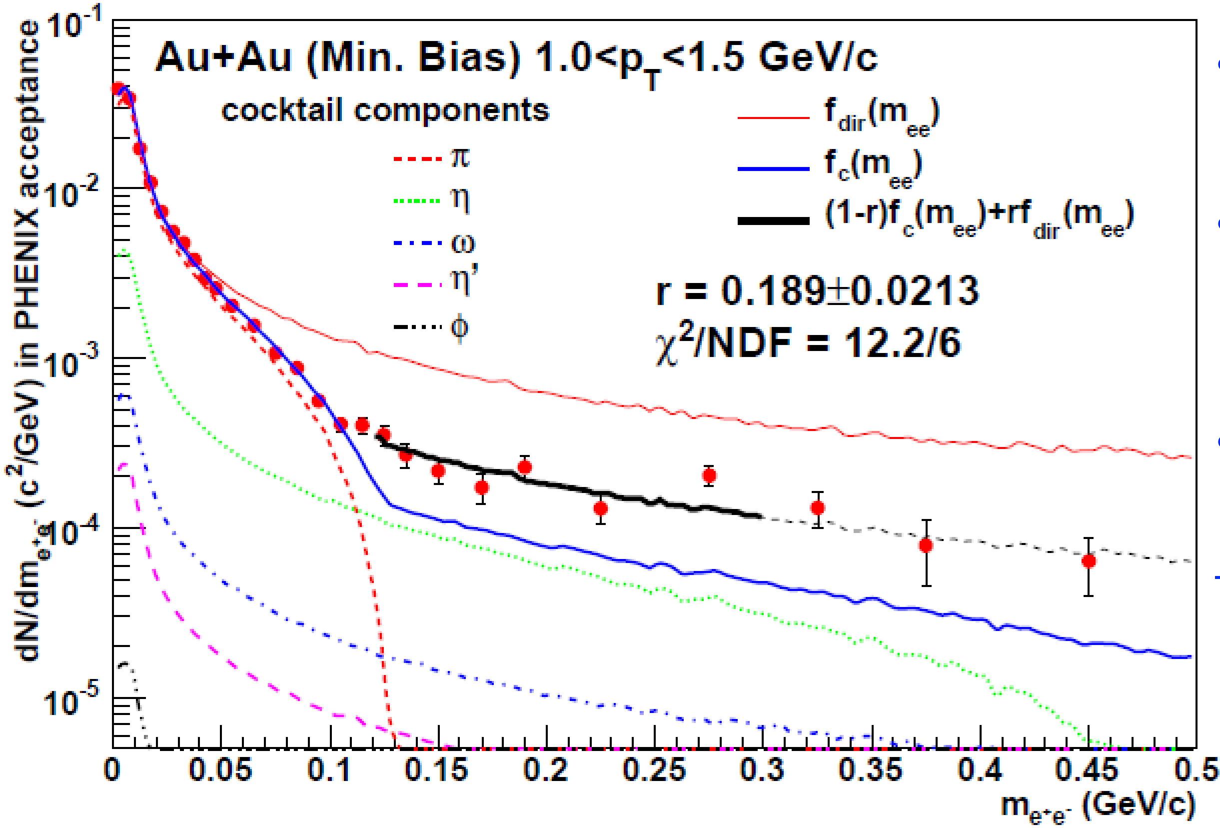
- Possible to separate hadron decay components from real signal in the proper mass window.

Determination of γ^* fraction, *r*

r = direct γ^*/inclusive γ^*

determined by fitting the following function for each p_T bin.

$$f_{data}(M_{ee}) = (1-r)\cdot f_{cocktail}(M_{ee}) + r\cdot f_{direct}(M_{ee})$$



- **f_{direct} is given by Kroll-Wada formula with *S* = 1.**
- **$f_{cocktail}$ is given by cocktail components**
- **Normalized to the data for m<30 MeV/c^2**
- **Fit in 120-300MeV/c^2 (insensitive to π^0 yield)**
  - **Assuming direct γ^* mass shape: χ^2/NDF=12.2/6**

arXiv:0804.4168
arXiv:0912.0244

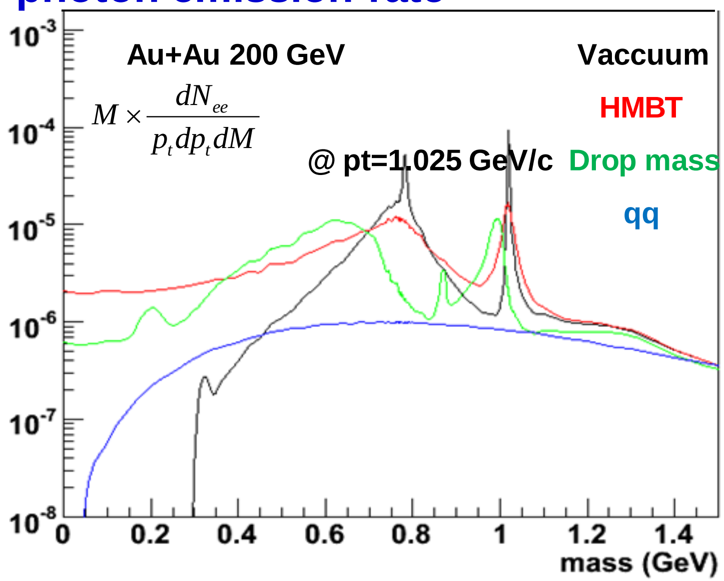
Direct measurement of $S(m_{ee}, p_T)$

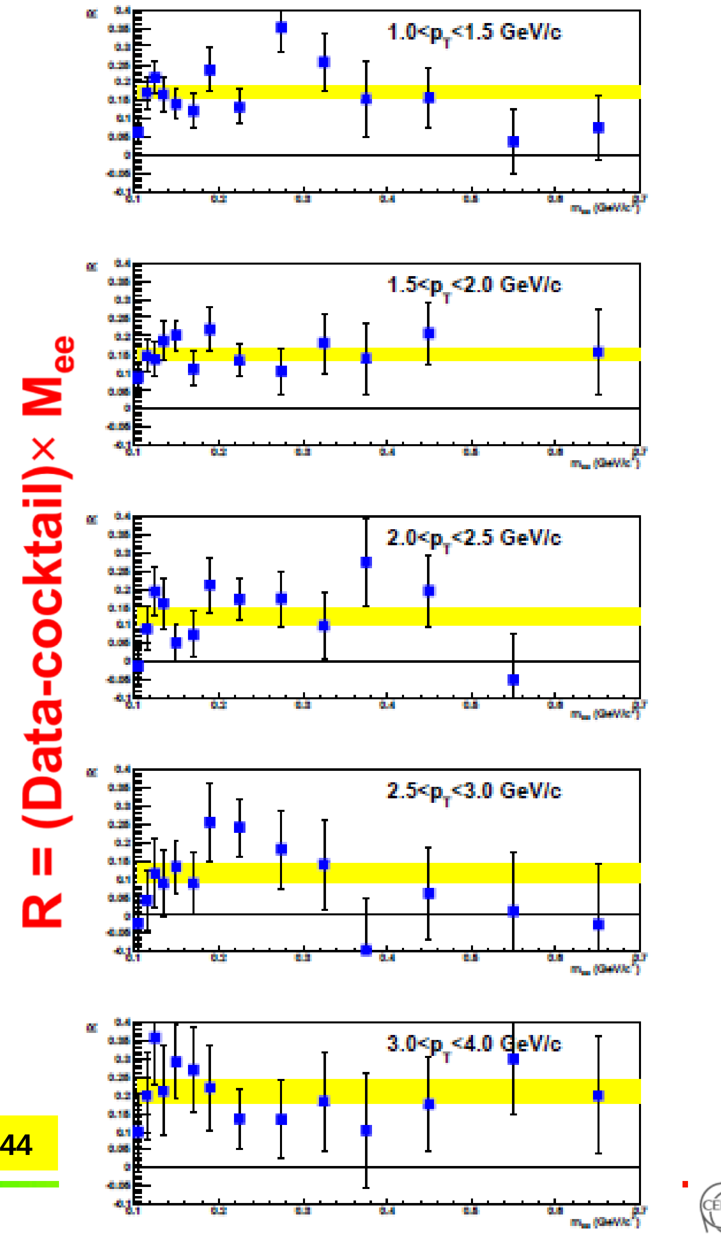
$$R(m, p_T) \simeq \frac{dN_{\gamma^*}^{\text{excess}}(m, p_T)}{dp_T} \Big/ \frac{dN_{\gamma}^{\text{incl}}(p_T)}{dp_T}$$
$$= S(m, p_T) dN_{\gamma}^{direct}(p_T) / dN_{\gamma}^{\text{incl}}(p_T)$$

No indication of strong modification of EM correlator at this high p_T region

(presumably the virtual photon emission is dominated by hadronic scattering process like $\pi+\rho \rightarrow \pi+\gamma^*$ or $q+g \rightarrow q+\gamma^*$)

Extrapolation to M=0 should give the real photon emission rate





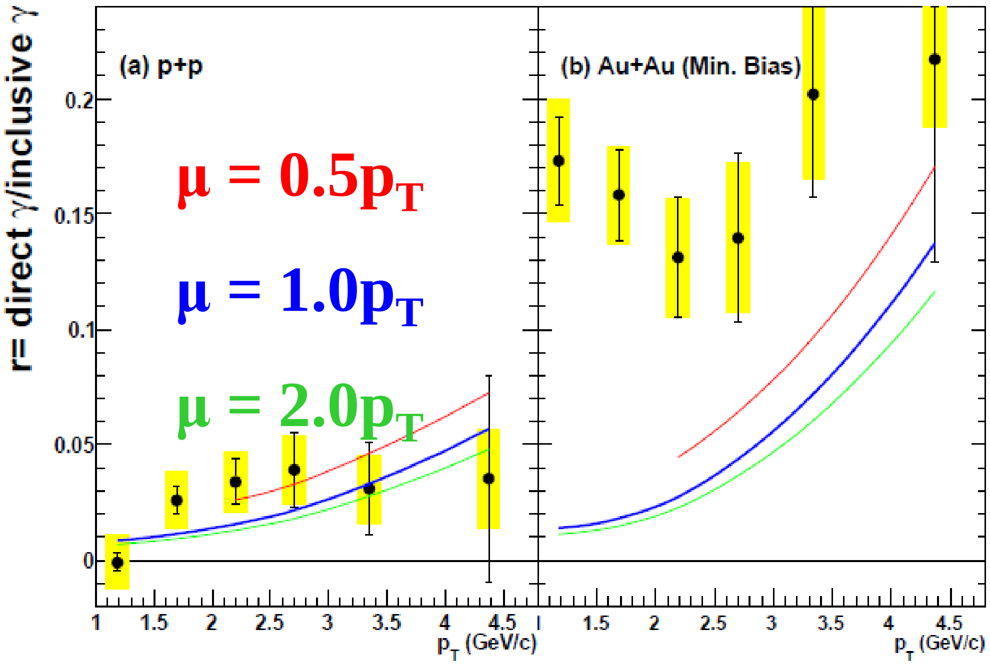
arXiv:0912.0244

direct γ^*/inclusive γ^*

arXiv:0804.4168

arXiv:0912.0244

p+p Au+Au



Base line

Curves : NLO pQCD calculations with different theoretical scales done by W. Vogelsang.

$$\left(d\sigma_{\gamma}^{NLO}/dp_T\right)/\left(d\sigma_{\gamma}^{NLO}/dp_T + d\sigma_{\gamma}^{hadron}/dp_T\right)$$

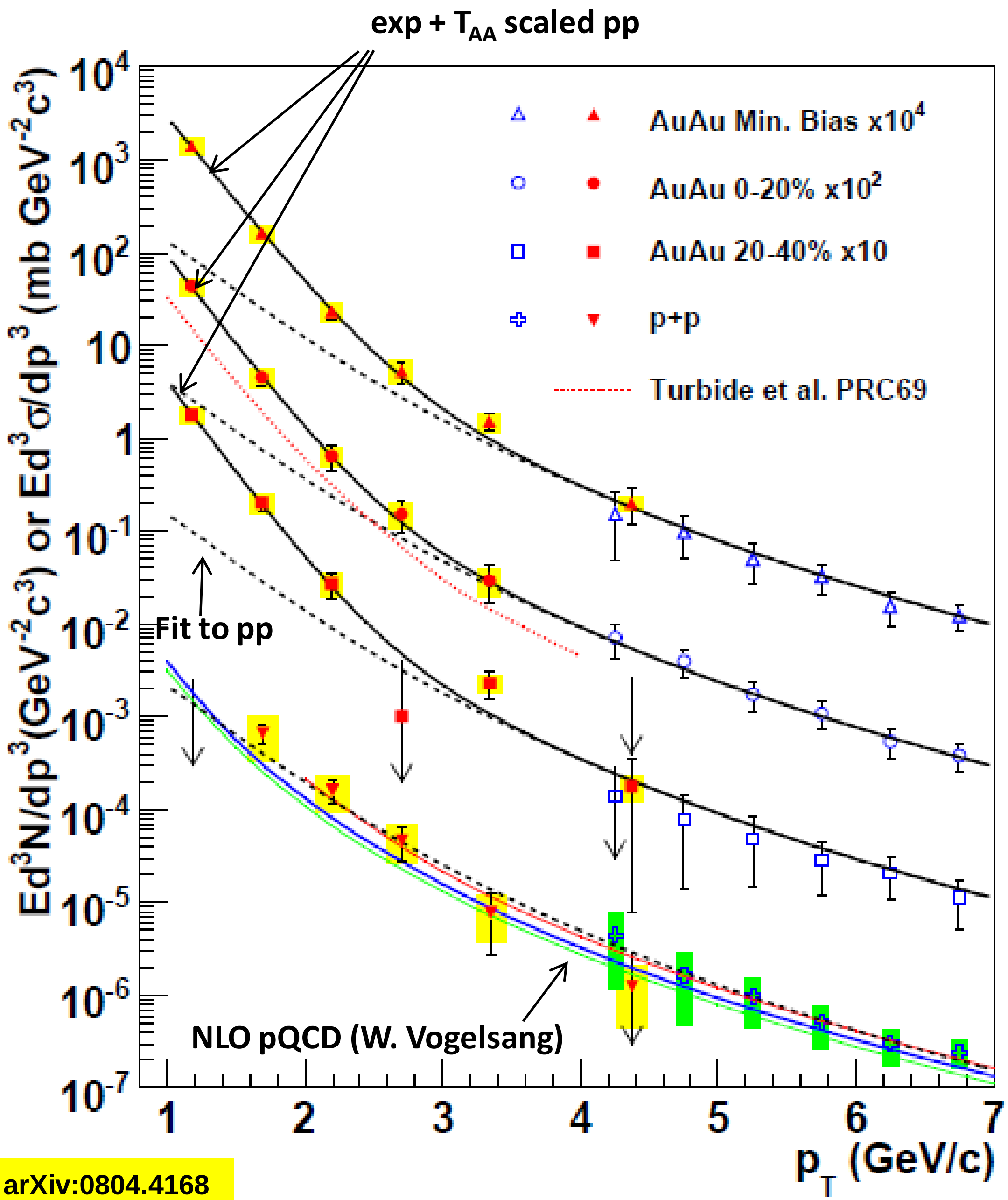
p+p

- Consistent with NLO pQCD
  – better agreement with small μ

Au+Au

- Clear enhancement above NLO pQCD

1st measurement of Thermal Radiation

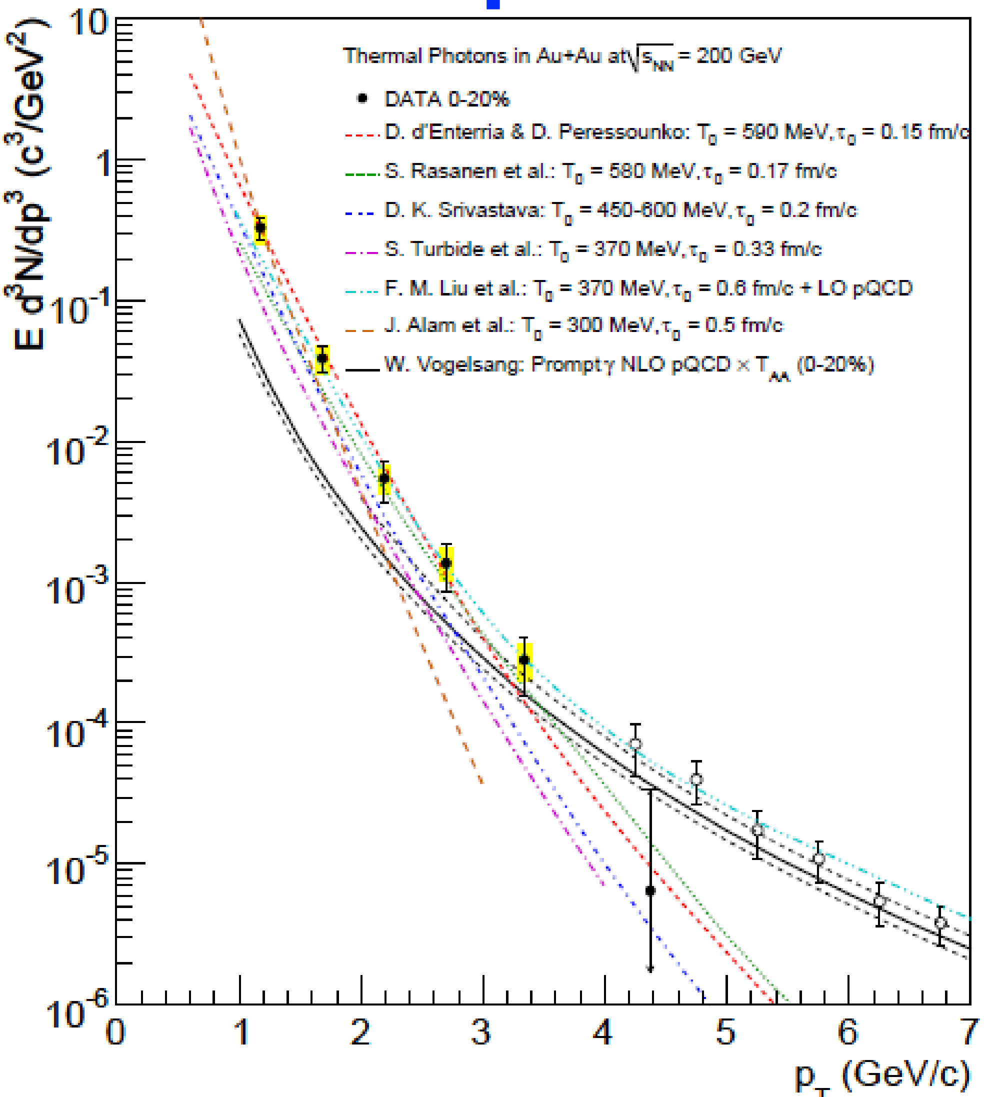


- **Direct photon**
  - –real (p_T>4GeV)
  - –virtual (1<p_T<4GeV & m_{ee}<300MeV)
- **pQCD consistent with p+p down to p_T=1GeV/c**
- **Au+Au above N_{coll} x p+p for p_T < 2.5 GeV/c**
- **Au+Au = pQCD + exp: $T_{ave} = 221 \pm 19^{stat} \pm 19^{syst}$**

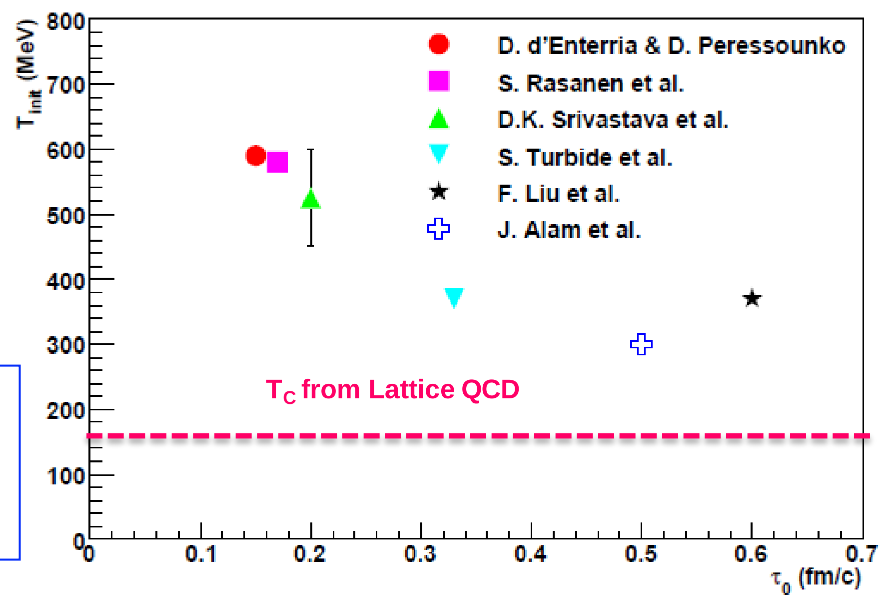
arXiv:0804.4168
arXiv:0912.0244

arXiv:0912.0244

Comparison to Hydro models



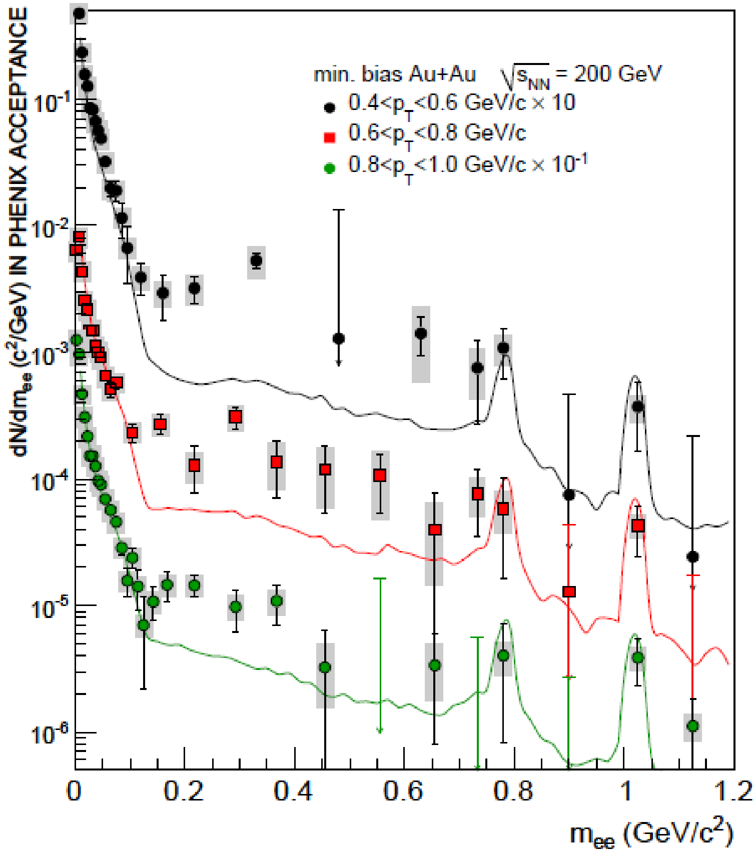
- From data: Au+Au = pQCD + exp:
  $T_{ave} = 221 \pm 19^{stat} \pm 19^{syst}$
- Comparison to hydrodynamical models:
  - p_T<3 GeV/c thermal contribution dominates over pQCD.
  - Assume formation of a hot QGP with
    300 MeV < T_{init} < 600 MeV
    0.6 fm/c < τ_0< 0.15 fm/c
  - Models reproduce the data within a factor of two.



From data: T_{ini} > 220 MeV > T_C
From models: T_{ini} = 300 to 600 MeV
τ_0 = 0.15 to 0.5 fm/c

LMR II

arXiv:0912.0244

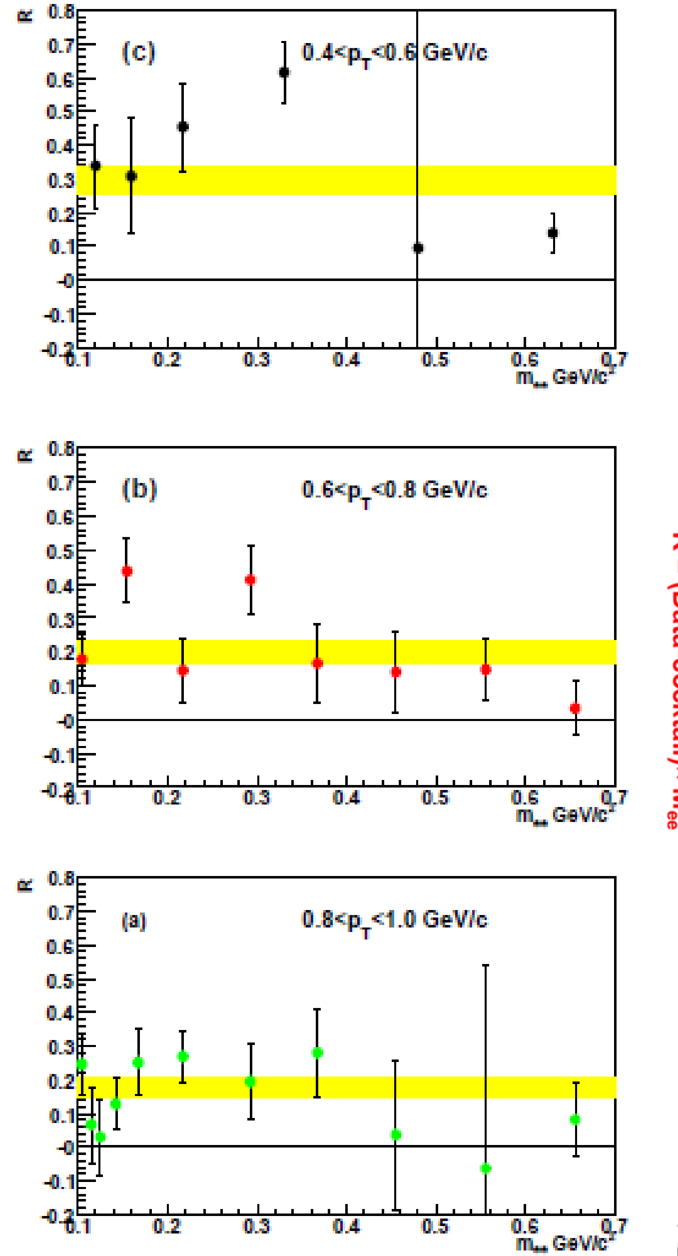


Large and broad enhancement
→ $S(m_{ee})$ no longer const

Towards lower p_T

- **Consistent with flat**
→$S(m_{ee})$ const
- **<R>=0.177±0.032**
- **Consistent with higher p_T values**

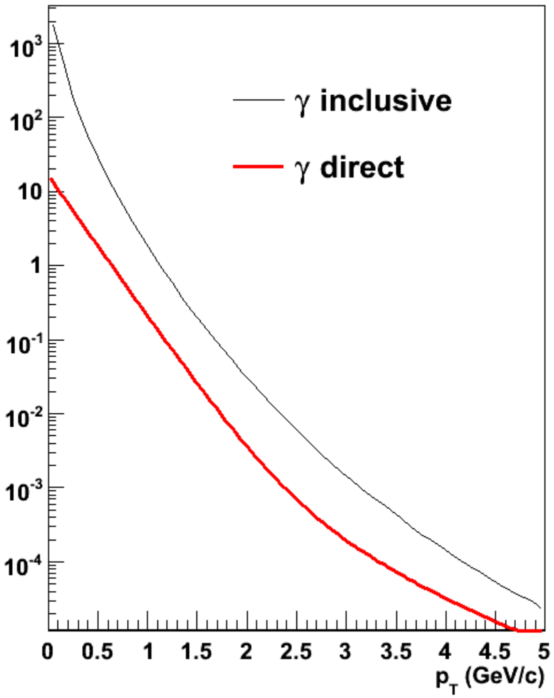
arXiv:0912.0244



Extrapolate the spectrum of direct photons

- For $0.8 < p_T < 1.0$ GeV/c
  $<R> = 0.177 \pm 0.032$
  consistent with higher p_T
- Decay photons spectrum
  steeper than direct γ spectrum

→ At lower p_T,
the expected direct photon fraction
r = direct γ / inclusive γ = direct γ / (direct + decay) $\gamma \leq 0.17$



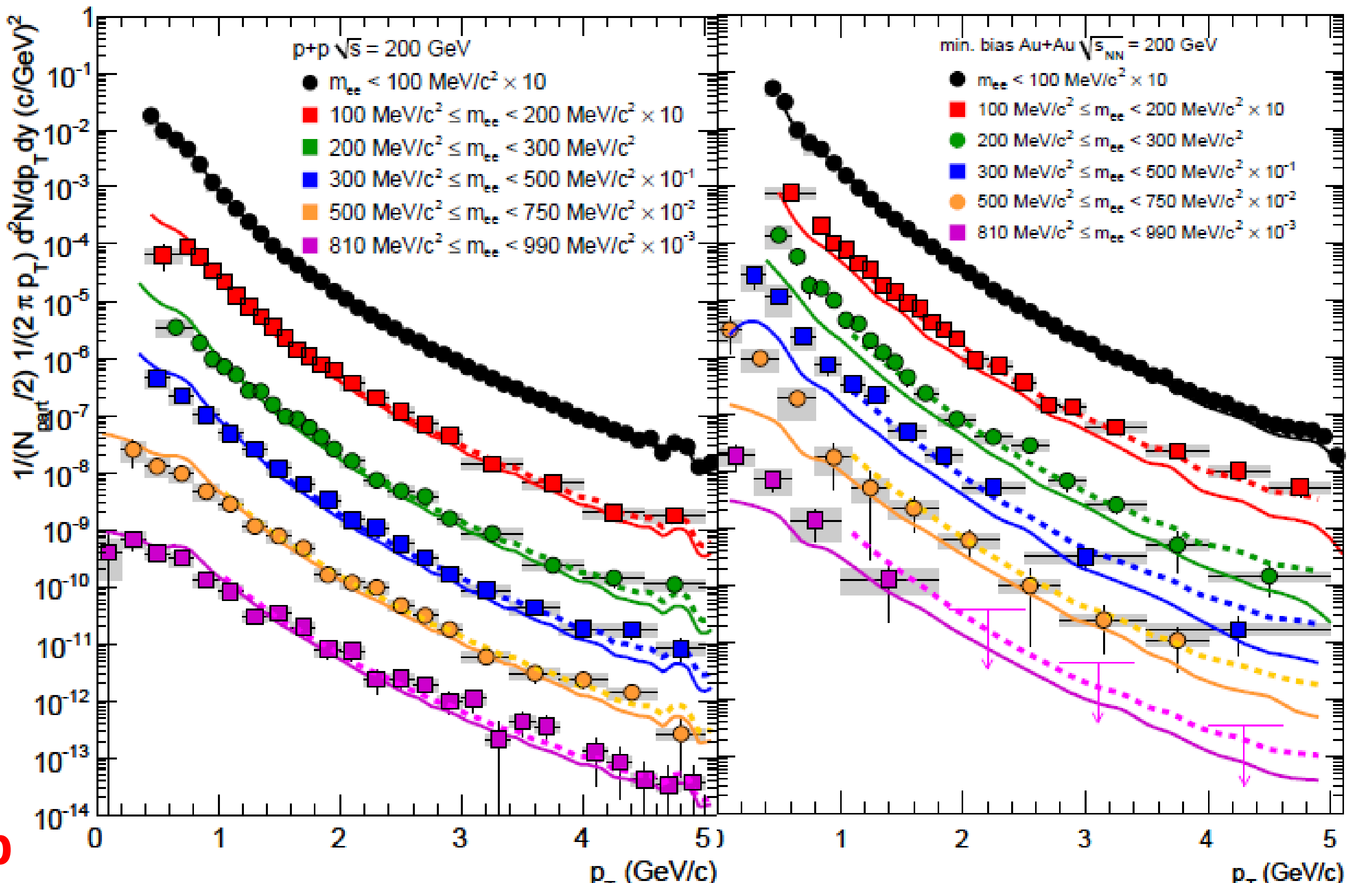
- For $0.4 < p_T < 0.6$ GeV/c
  $R(m) > 0.17$

→The enhancement in the low p_T region is larger than that expected from internal conversion of direct photons.

arXiv:0912.0244

Dilepton Spectra

p+p Au+Au



Acceptance-corrected

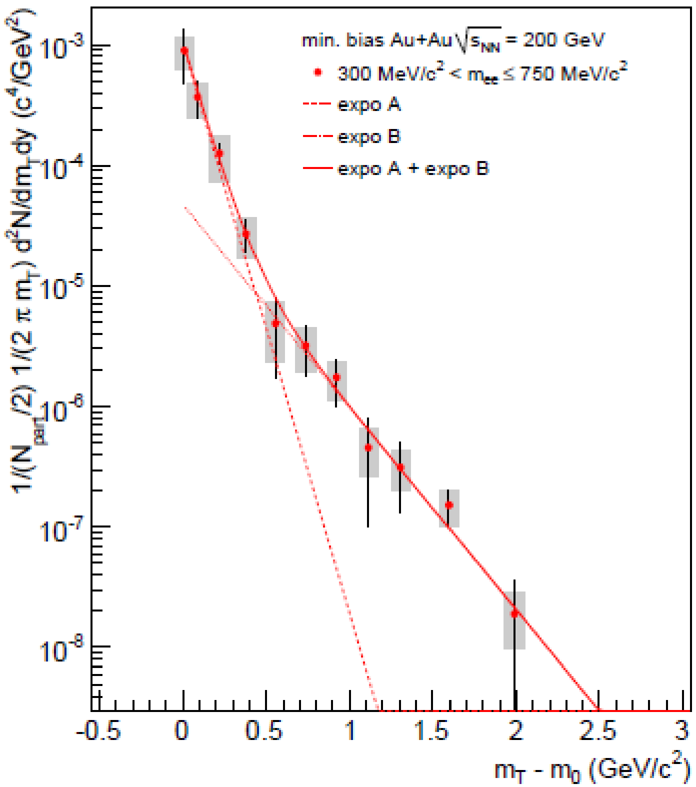
- **p+p**
  - Agreement with cocktail + internal conversion of direct photons
- **Au+Au**
  - p_T>1GeV/c: small excess → internal conversion of direct photons
  - p_T<1GeV/c: large excess for $0.3<m_{ee}<1$ GeV

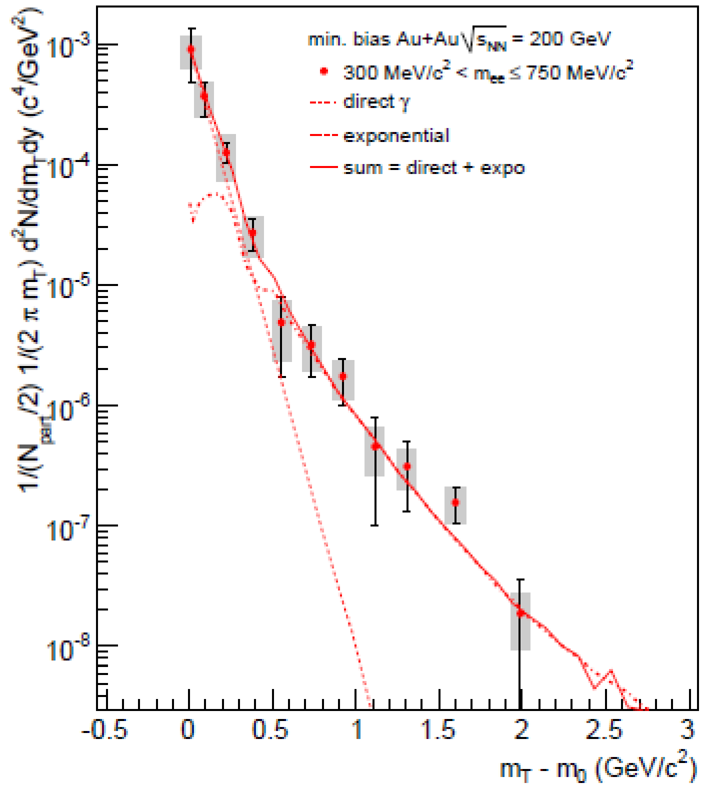
→Low temperature component with strong modification of EM correlator?

Average Temperature of the sources

arXiv:0912.0244

- $m_T - m_0$ spectrum of Excess = Data – (cocktail+charm)
- Fit: $\frac{d^2N}{2\pi m_T dm_T dy} = A_1 \cdot \exp - \frac{m_T}{T_1} + A_2 \cdot \exp - \frac{m_T}{T_2}$ or $\frac{d^2N}{2\pi m_T dm_T dy} = A_1 \cdot \exp - \frac{m_T}{T_1} + .$ Direct γ





T_2 consistent with T_γ

T_1 = 92.0 ± 11.4^{stat} ± 8.4^{syst} MeV
T_2 = 258.4 ± 37.3^{stat} ± 9.6^{syst} MeV
χ^2/NDF= 4.00/9

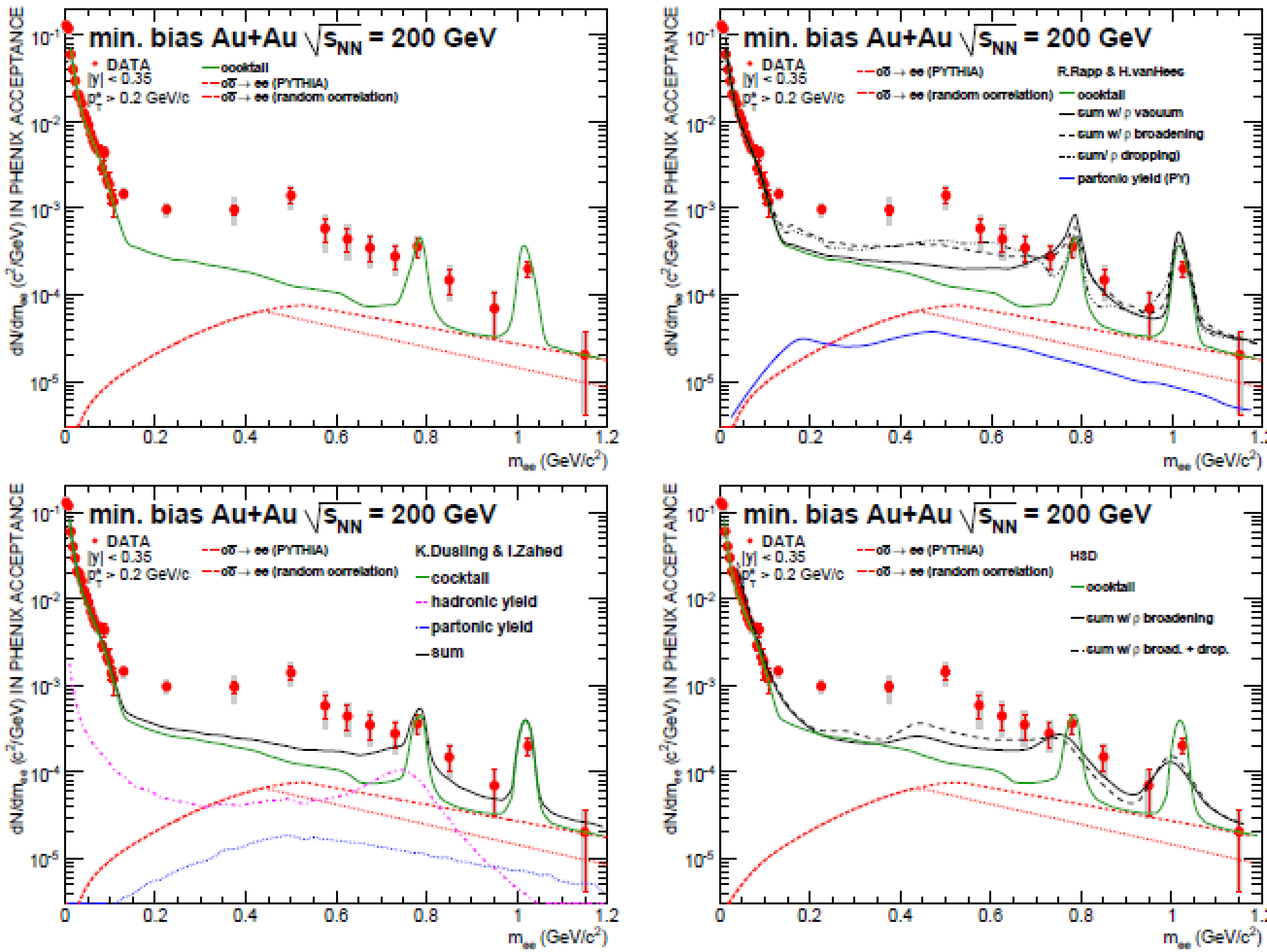
T_1 = 86.5 ± 12.7^{stat} $^{+11.0}_{-28.4}$^{syst} MeV
T_γ = 221 ± 19^{stat} ± 19^{syst} MeV
χ^2/NDF= 16.6/11

low mass enhancement has inverse slope of ~100 MeV.

Theory comparison

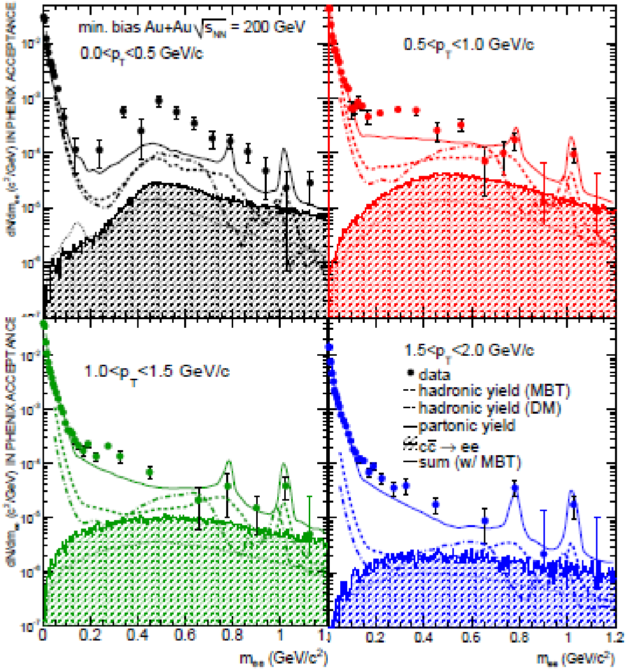
- $\pi\pi$ annihilation + modified ρ spectral function
  - Broadening
  - Mass shifting
  - Both
- Insufficient to explain data

arXiv:0912.0244



arXiv:0912.0244

Theory comparison II

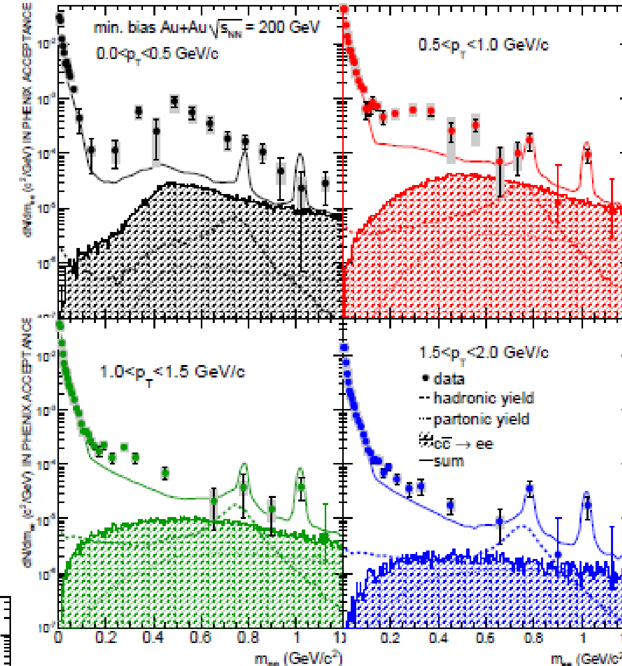


High p_T region:
here we isolated a contribution arising from

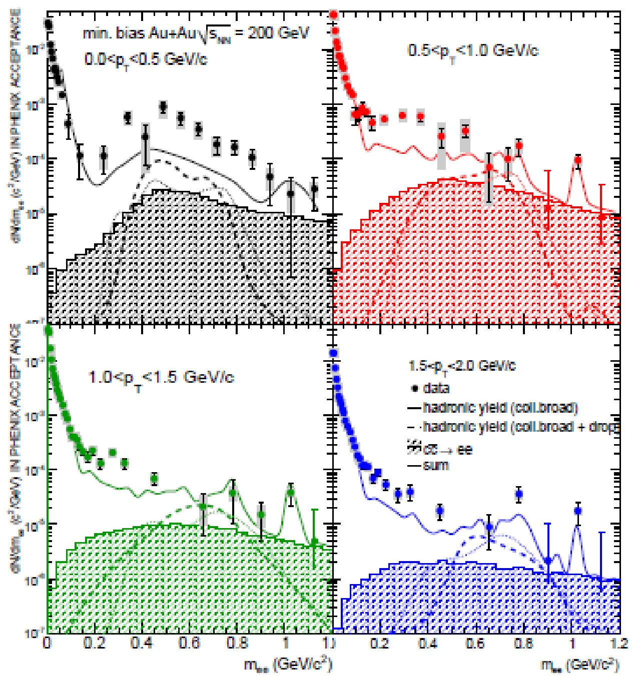
- **$\pi+\rho \rightarrow \pi+\gamma^*$**
(typically included)

or

- **$q+g \rightarrow q+\gamma^*$**
(not included so far)



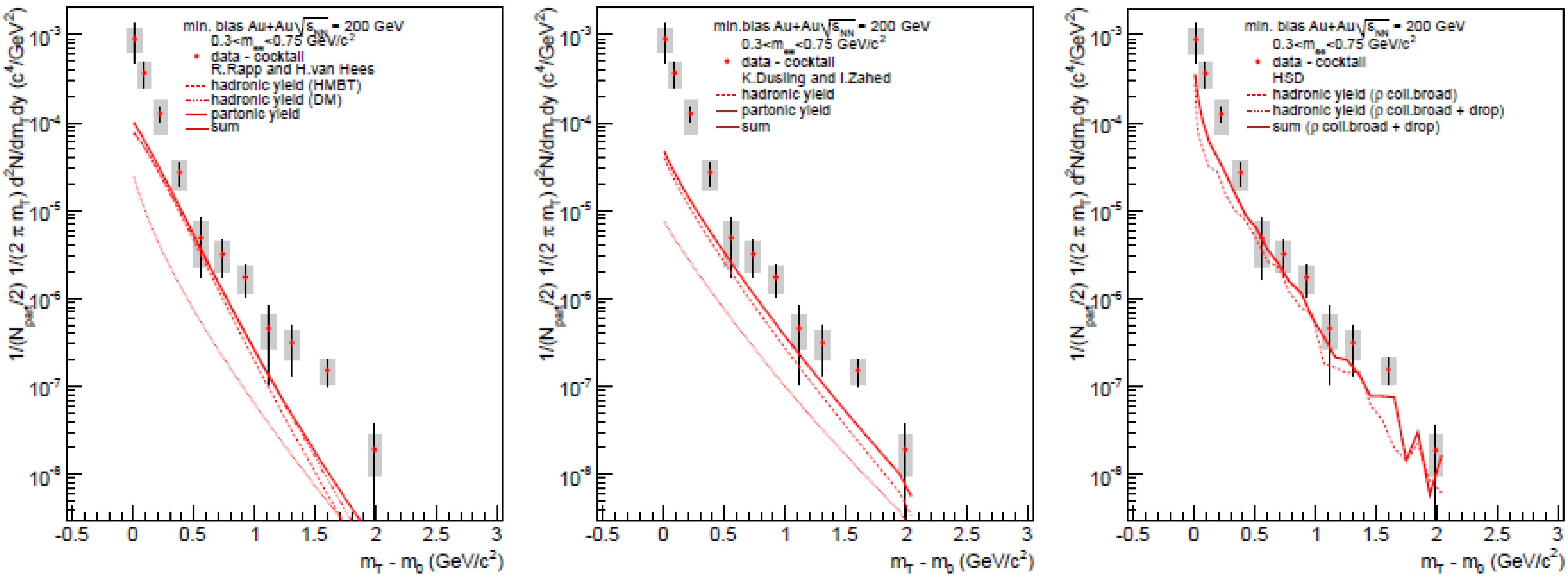
Even when looking differentially in various p_T bins the theoretical calculations are insufficient to explain the data



Low p_T region:
where the enhancement becomes large and its shape seems incompatible with unmodified $q+g \rightarrow q+\gamma^*$

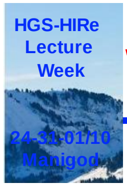
arXiv:0912.0244

Theory comparison III



- The theoretical calculations are insufficient to explain the data
- High p_T: they are too soft (except for HSD which does not include partonic contribution)
- Low p_T: they are too hard to explain the enhancement (T~100 MeV)

what is missing ?



Summary

- EM probes ideal "penetrating probes" of dense partonic matter created at RHIC
- Double differential measurement of dilepton emission rates can provide
  - Temperature of the matter
  - Medium modification of EM spectral function
- PHENIX measured dilepton continuum in p+p and Au+Au

p+p

Low Mass Region

- Excellent agreement with cocktail

  - LMR I
    deduce photon emission in agreement with pQCD

  - LMR II
    Excellent agreement with cocktail

Intermediate Mass Region

- Extract charm and bottom cross section

Au+Au

Low Mass Region

- Enhancement above the cocktail $4.7 \pm 0.4^{stat} \pm 1.5^{syst} \pm 0.9^{model}$

  - LMR I
    deduce photon emission exponential above pQCD, T>200 MeV

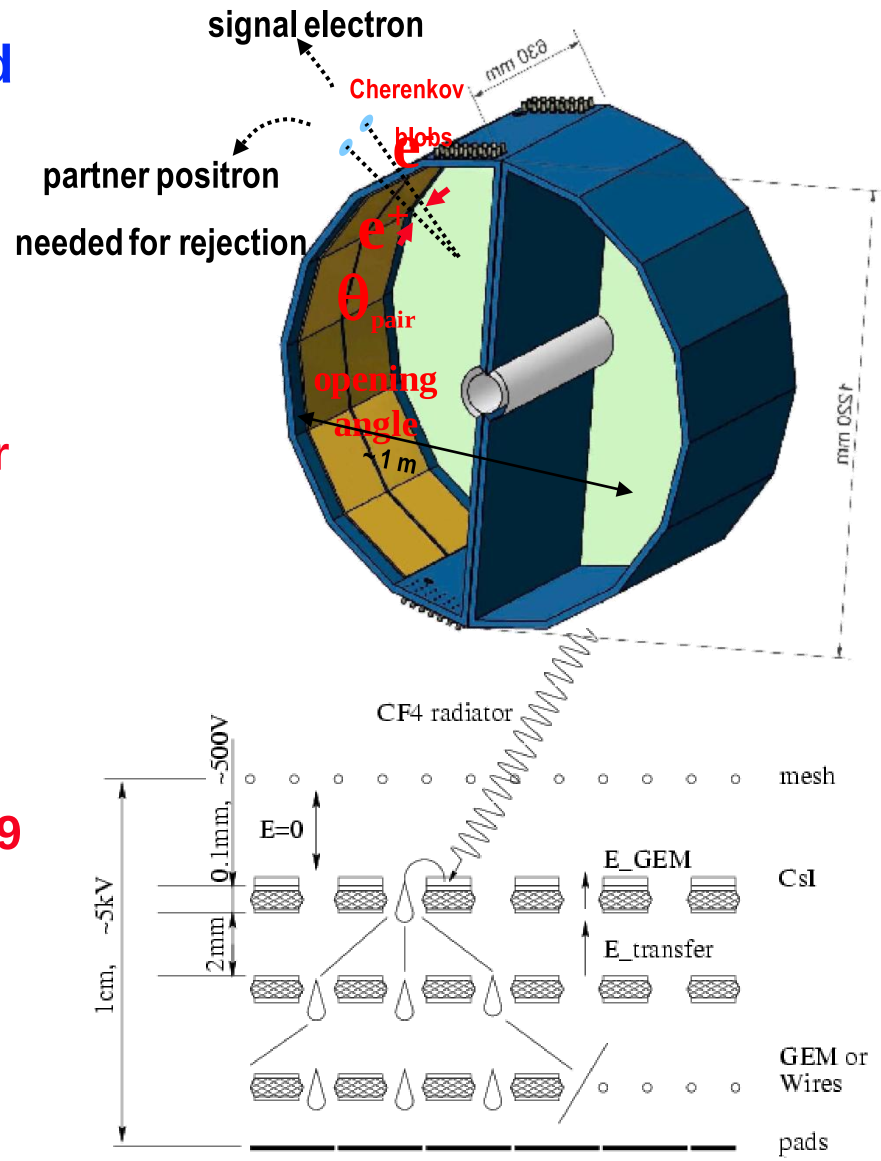
  - LMR II
    - Centrality dependency: increase faster than N_{part}
    - p_T dependency: enhancement concentrated at low p_T, T ~ 100 MeV

Intermediate Mass Region

- Agreement with PYTHIA: coincidence?

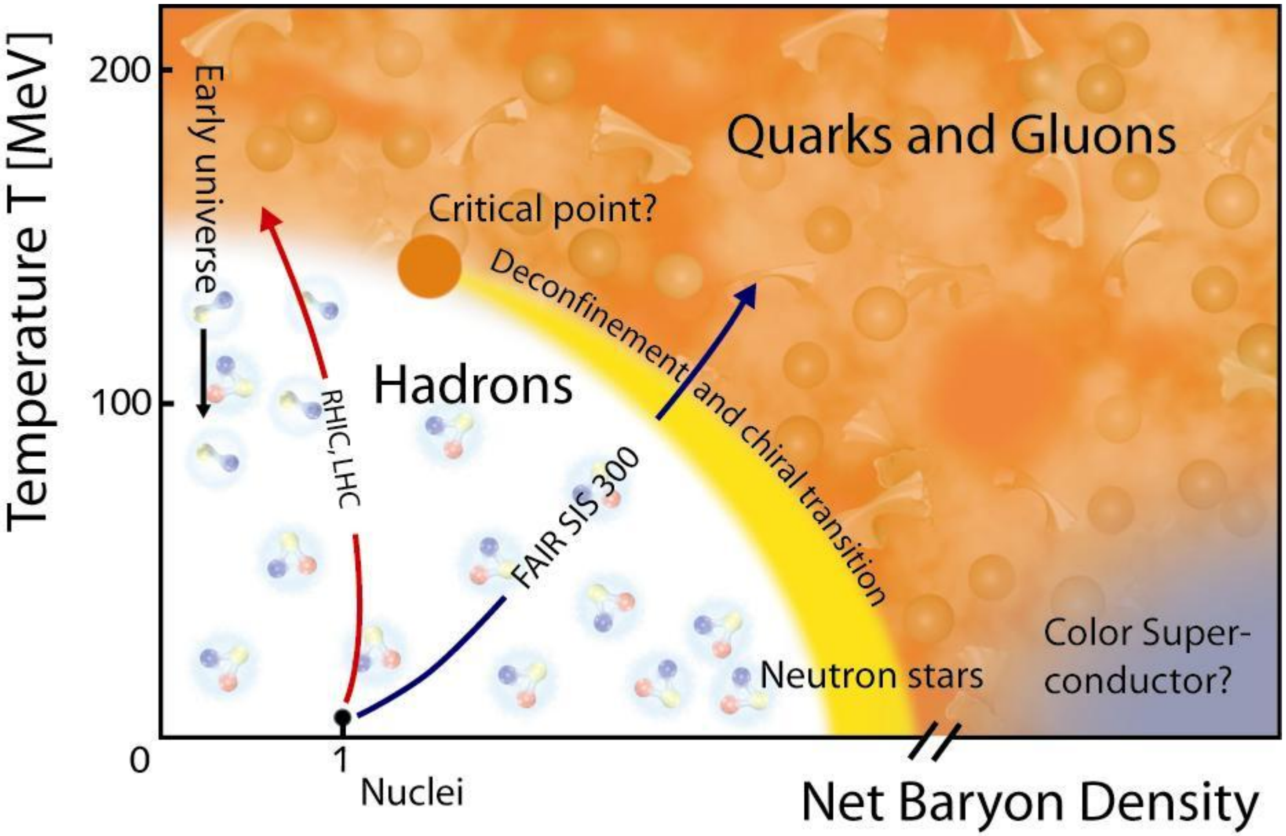
Near-Future Measurements at RHIC

- **Improve measurement in the LMR**
  → reduce combinatorial background
  → Hadron Blind Detector:
  Dalitz rejection via opening angle
  - **identify $e^{\pm}$ in field free region**
  - **veto signal $e^{\pm}$ with partner**
- **HBD concept**
  - **windowless CF4 Cherenkov detector**
  - **50 cm radiator length**
  - **CsI reflective photocathode**
  - **triple GEM with pad readout**
- **HBD time scale**
  - **Proof of principle in 2007**
  - **Successful data taking with p+p 2009**
  - **Ready for Au+Au in 2010**
- **Improve measurement in the IMR**
  → disentangle charm and thermal contribution
  → Silicon Vertex Detector



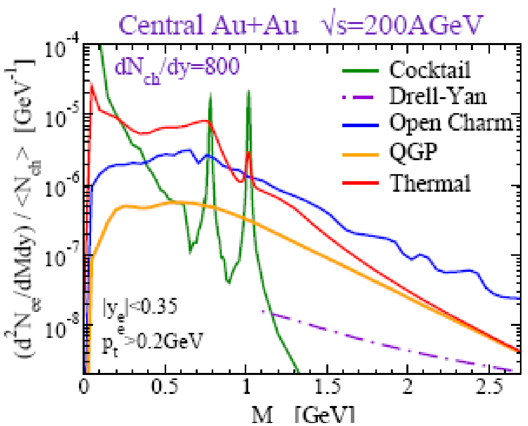
Future

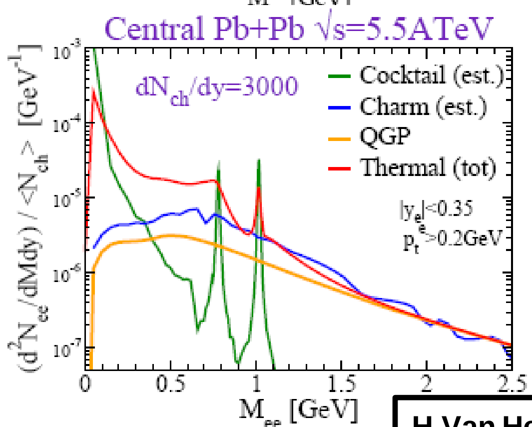
- **dielectron measurements in high energy HI collisions**
  - **go to even higher energy, i.e. maximum temperature → LHC**
  - **go back to lower energy, i.e. maximum baryon density → FAIR**
  - **stay at RHIC**
    - **HBD (and silicon vertex upgrades) for improved experiments at maximum RHIC energy**
    - **“low energy” program, i.e. use RHIC as a storage ring instead of an accelerator**



EM Probes at LHC

DILEPTONS





H.Van Hees and R.Rapp

PHOTONS

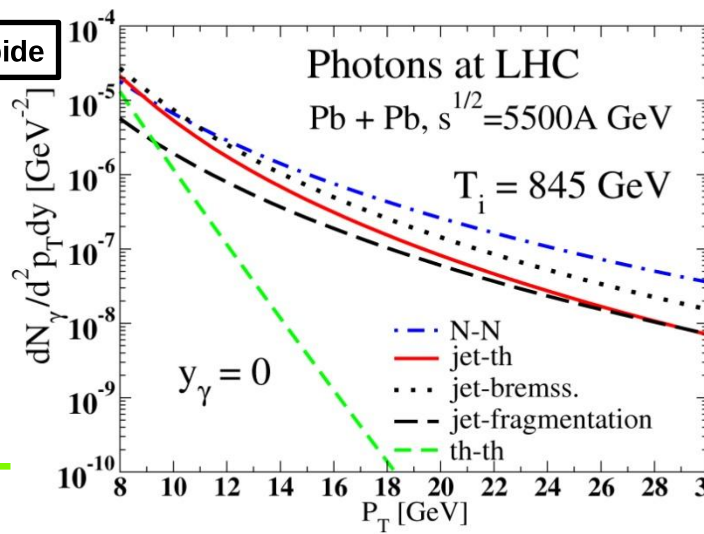
Low p_T

- Thermal/bulk photons (QGP + hadronic phase)
- Photons from jet-medium interactions
  - Jet-photon conversion, Induced photon bremsstrahlung
  - Cross sections forward/backward peaked
  - Yields approximately proportional to the jet distributions → Sensitivity to *early* time jet distributions
  - Longer path lads to increased production → Negative v2

High p_T

- Prompt photons from initial hard processes
  - No final state effects at all.
- Fragmentation/vacuum bremsstrahlung
  - Sensitivity to medium effects in the final state

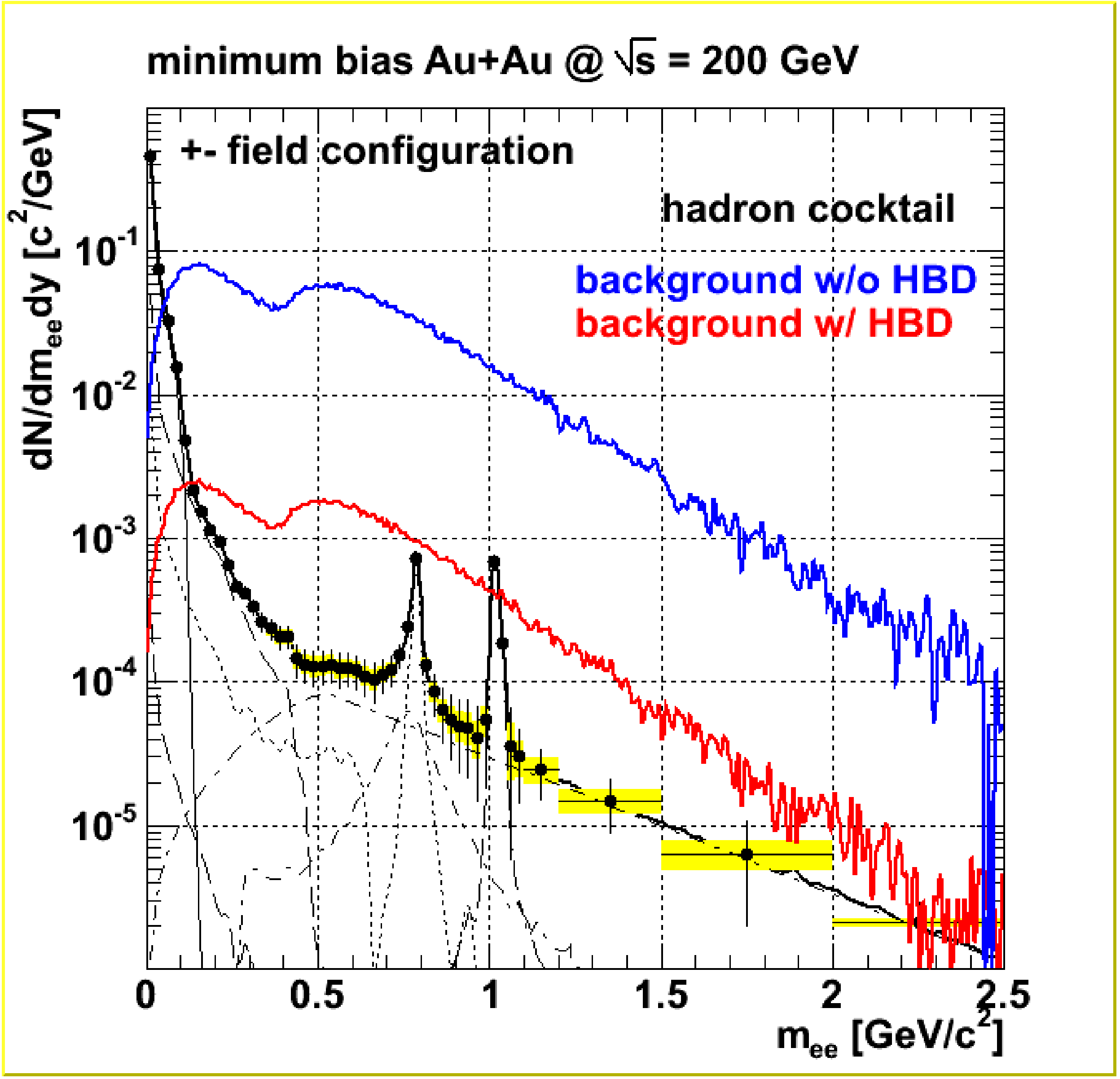
S.Turbide



- **At higher dN/dy thermal radiation from hadron gas dominant for m<1GeV**
- **For m>1GeV relatively stronger QGP radiation: comparable to DD but energy loss???**

Projections for RHIC: high energy

- impact of the HBD & modified B field at top energy
- recorded collisions
  - 10^9
  - 10^{10}



Projections for RHIC: low energy

- collision rates decrease with decreasing beam energy
  - ~40 Hz @ 8.6 GeV/u
  - 2 weeks run time gives ~50M events
  - HBD 'eliminates' sys. uncertainty
  - electron cooling in RHIC can increase the collision rate by a factor 10 → ~500M events in 2 weeks

→very promising!!!